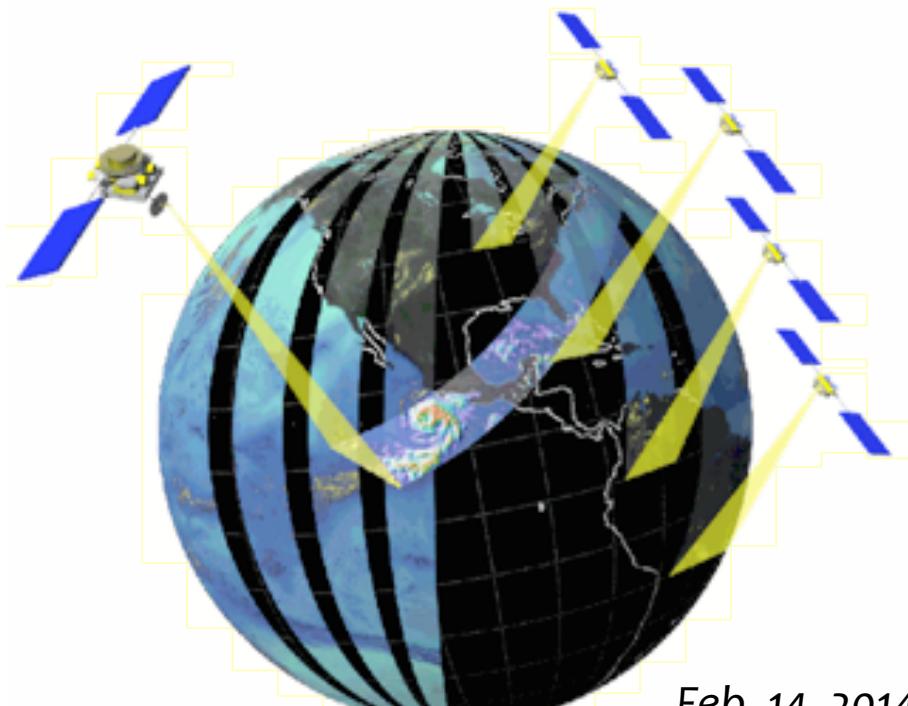


# Water in a Changing Climate

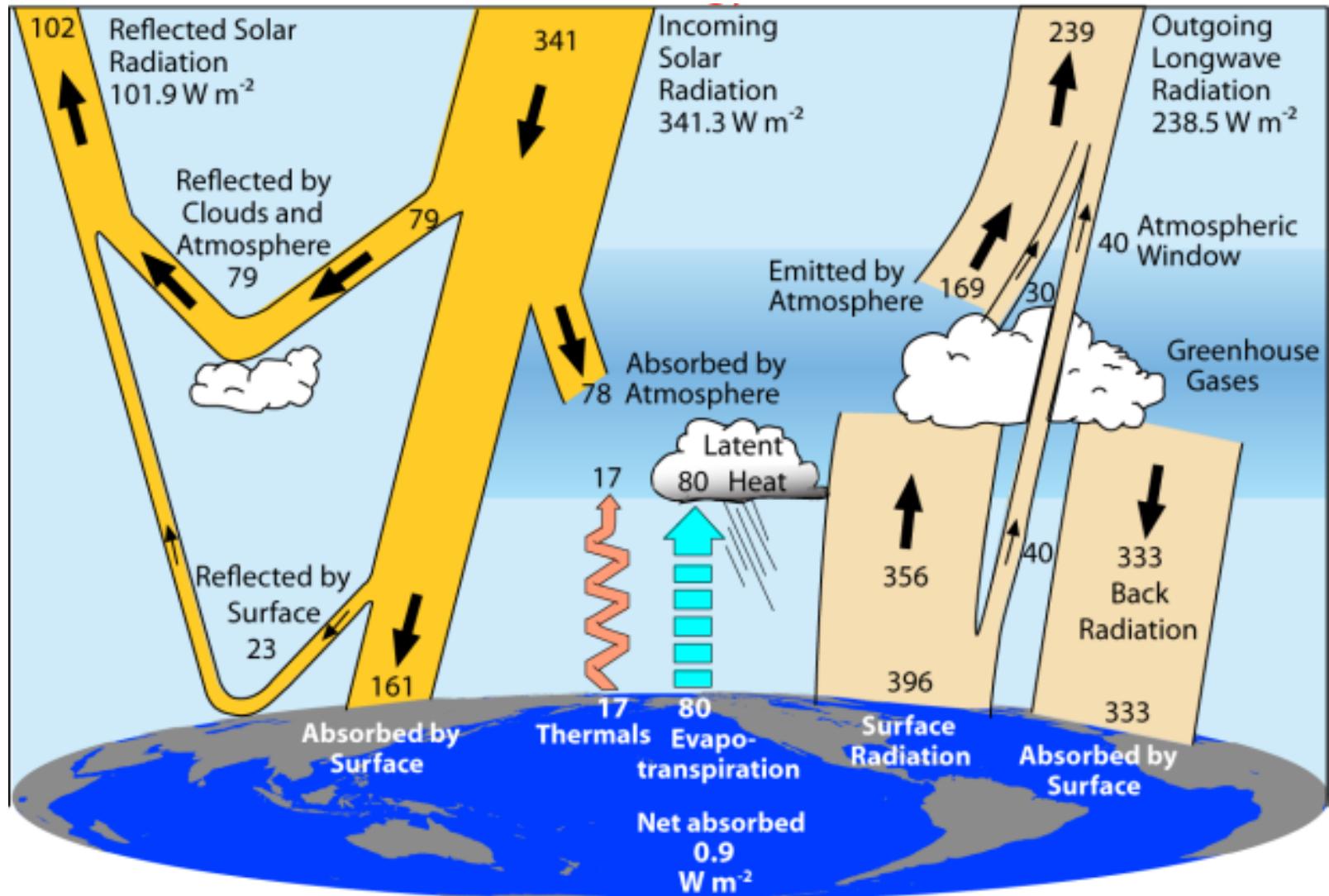
Christian Kummerow  
Dept. of Atmospheric Science  
Colorado State University



Feb. 14, 2014  
Global Precipitation Mission

Colorado  
State  
University

# The Global Energy Flows





## GEWEX Radiative Flux Assessment (RFA)

A project of the World Climate Research Programme  
Global Energy and Water Cycle Experiment  
(GEWEX) Radiation Panel

### Lead Authors:

#### Ehrhard Raschke

Max-Planck-Institute for Meteorology, Hamburg, and Institute for Meteorology of University of Hamburg, Germany,

#### Stefan Kinne

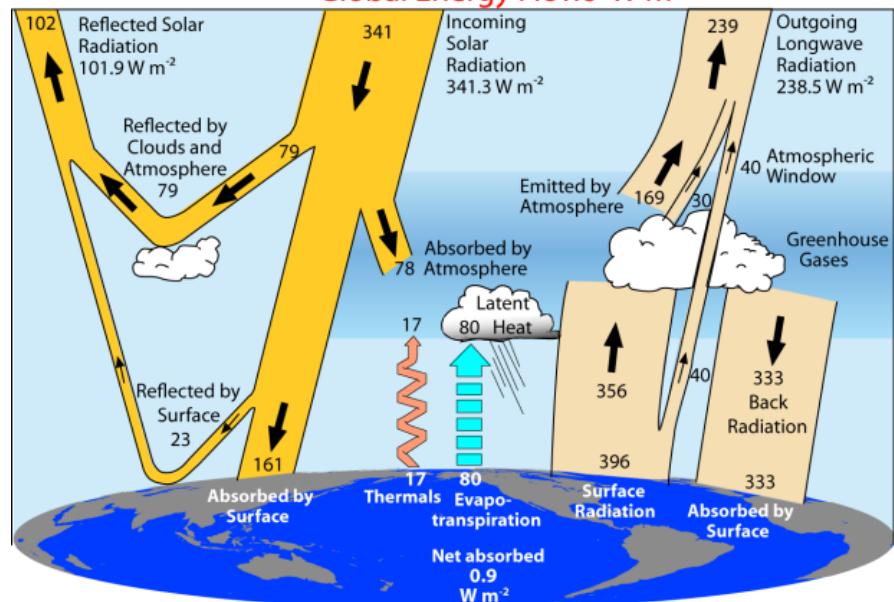
Max-Planck-Institute for Meteorology, Hamburg, Germany

#### Paul W. Stackhouse

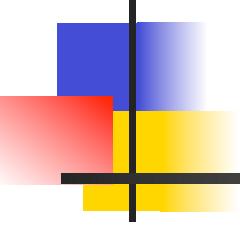
NASA, Langley Research Center, Hampton, Virginia, USA

January 2012  
WCRP-???

WMO/TD-No. ????



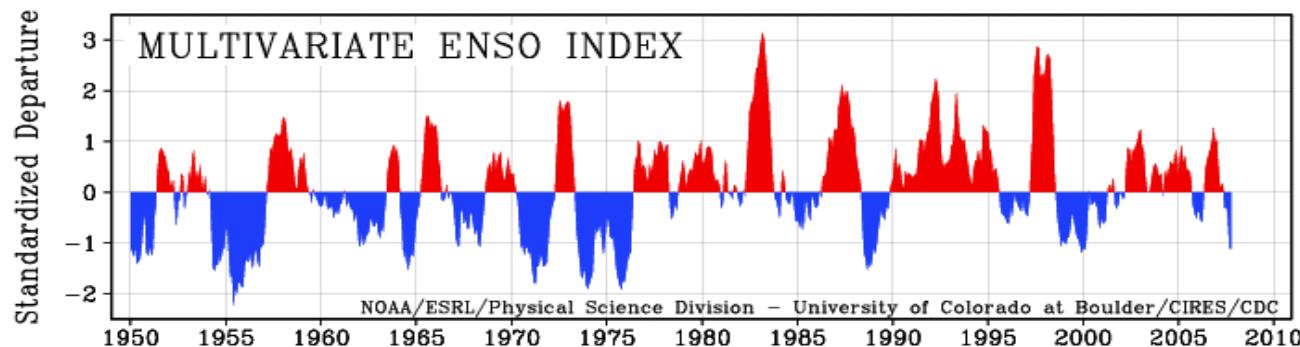
TFK	161	396	333
RFA	166.5	396.0	343.9
A-TRAIN		~350	



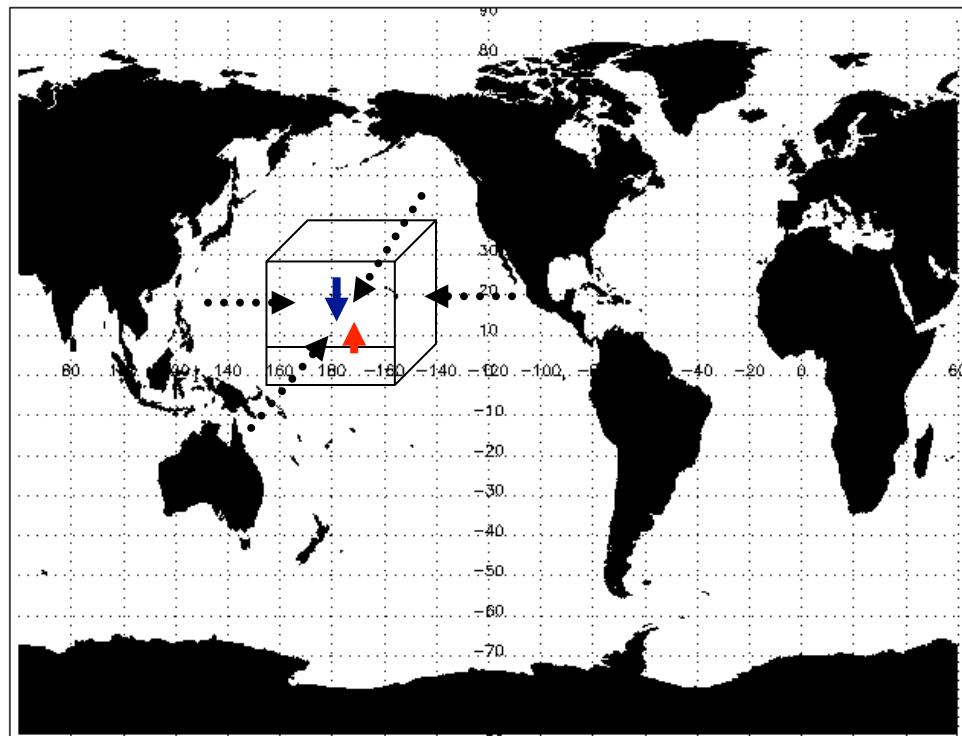
# Precipitation

- Absolute magnitude is now off by 20-25% relative to radiative fluxes. GEWEX working on next version w. consistent assumptions. Will publish in 2013.
- GEWEX's GPCP shows virtually no trend in global precipitation (~0.05%/decade). Wentz et al. (Science, 2007) shows significant trend (~1.4% /decade)
- Can also look at precipitation (=evaporation) and ask a simple question: Can we observe changes in precipitation and, if so, how confident are we that the changes are real rather than artifacts of the observing systems or algorithms?

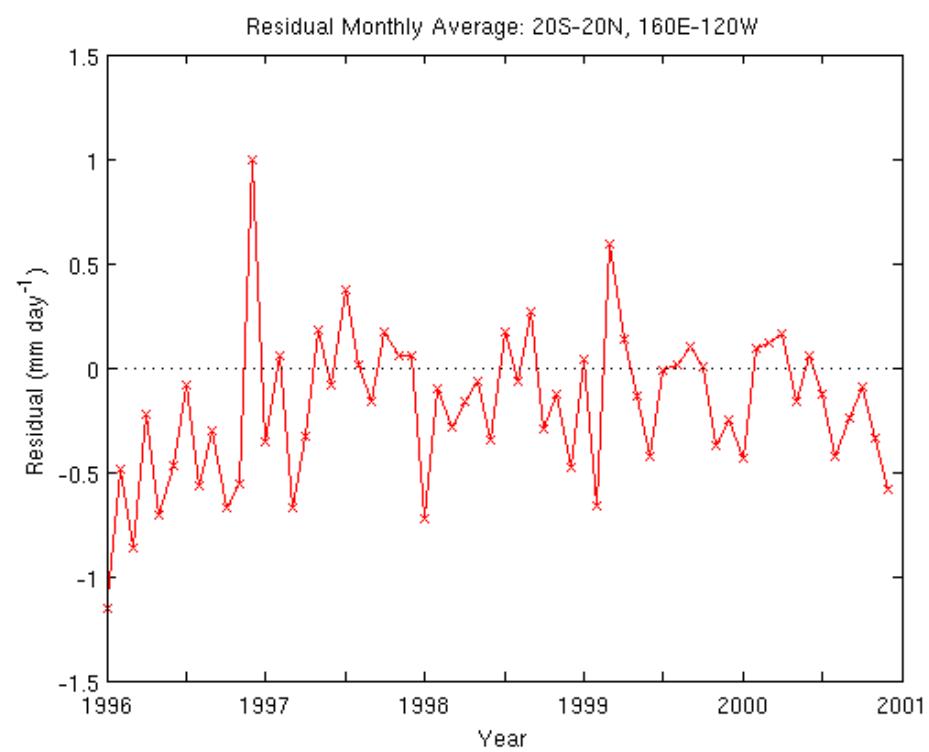
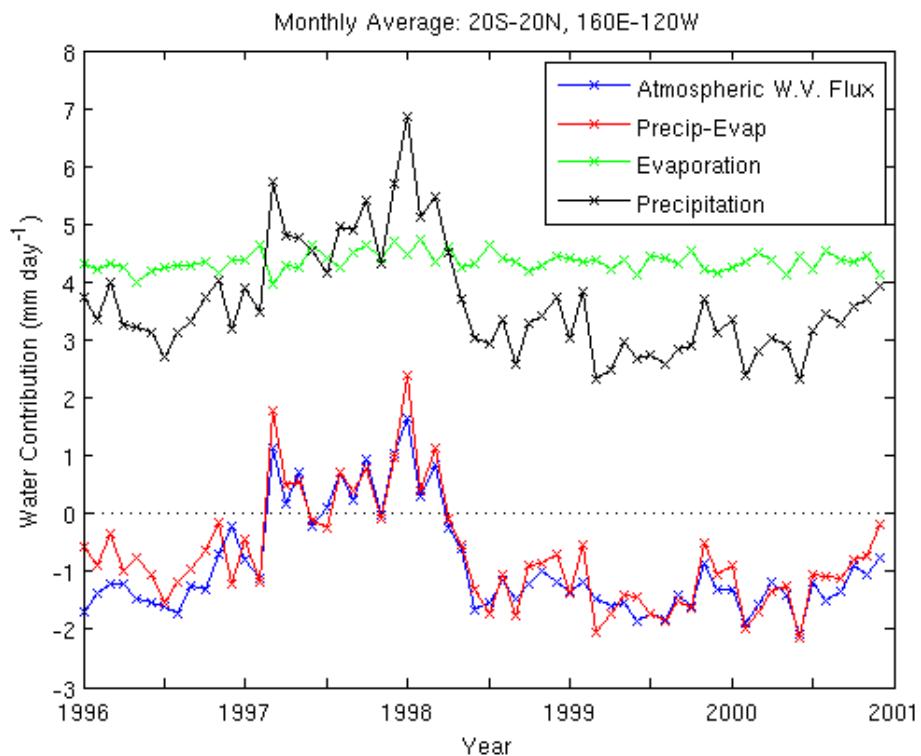
# Does the Water budget ( $Q+E = P$ ) close?



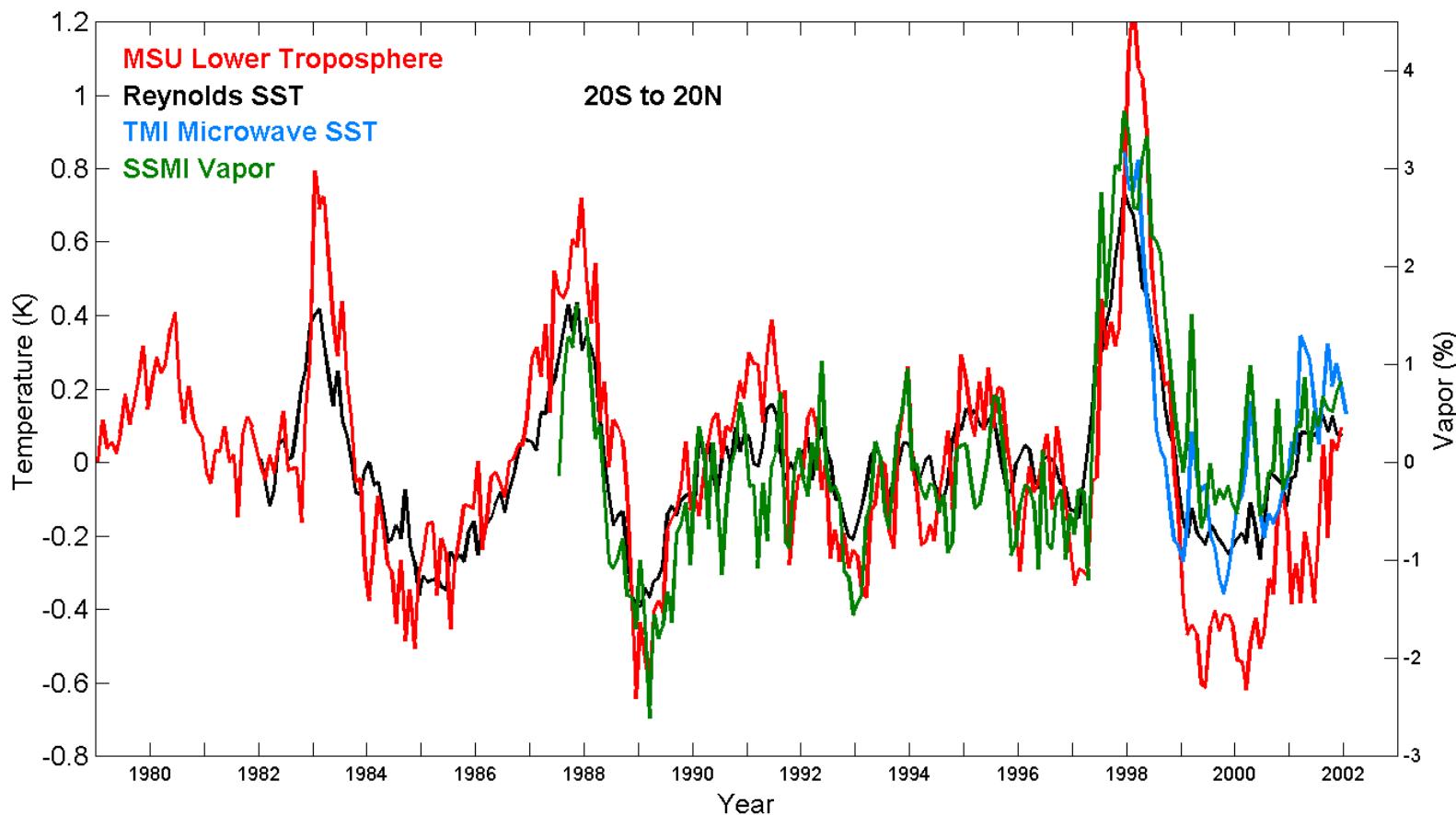
- Monthly means from 96 Jan through 00 Dec
- $20^{\circ}\text{N}-20^{\circ}\text{S}$ ,  $160^{\circ}\text{E}-120^{\circ}\text{W}$



# The Central Pacific Water Budget



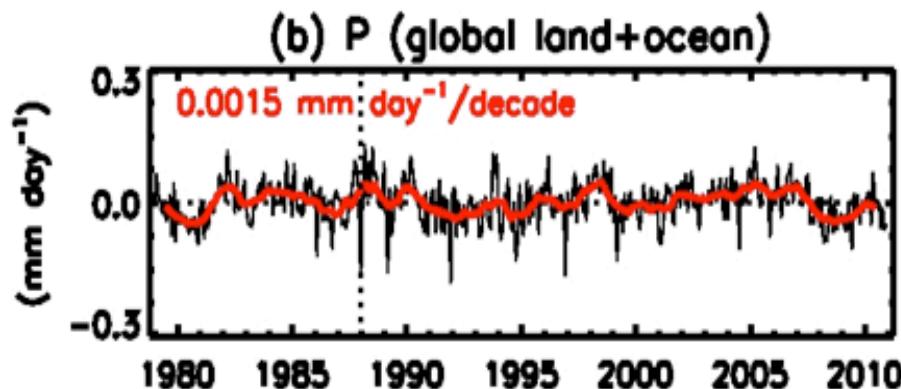
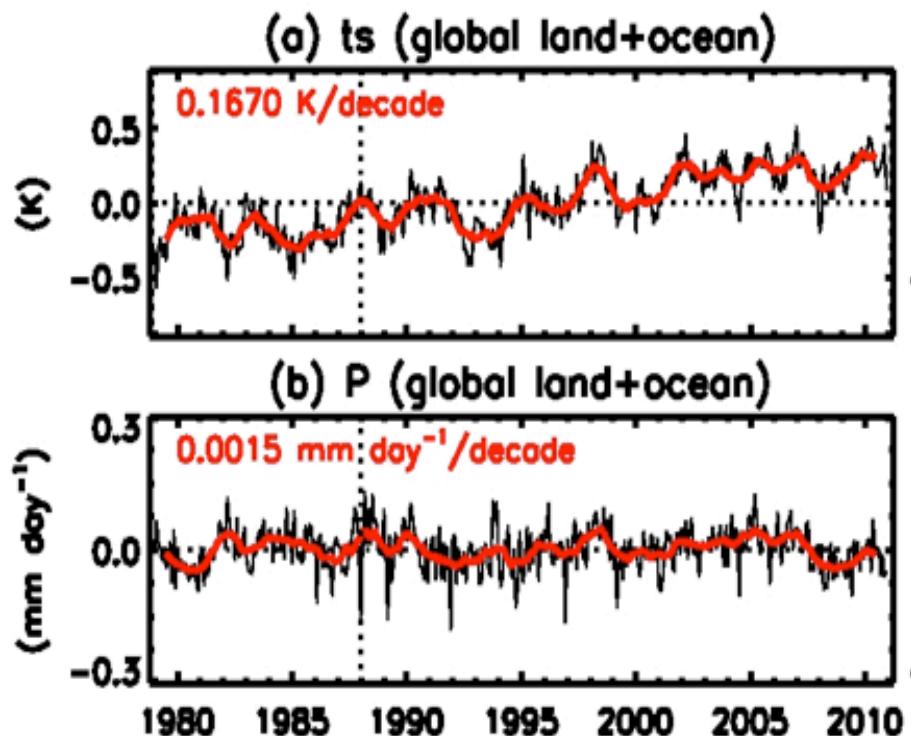
# Water Vapor and SST



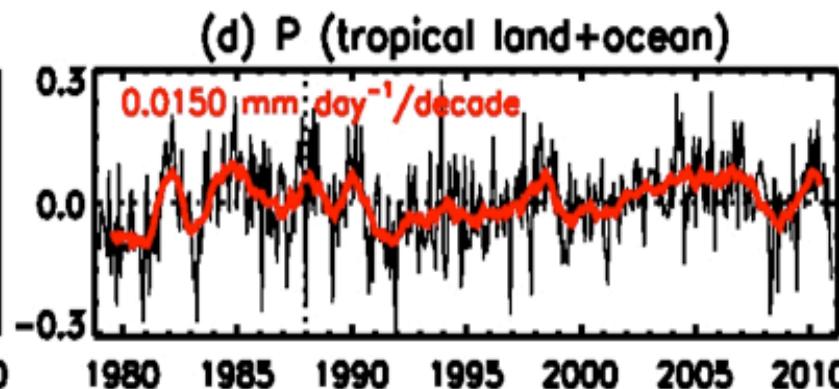
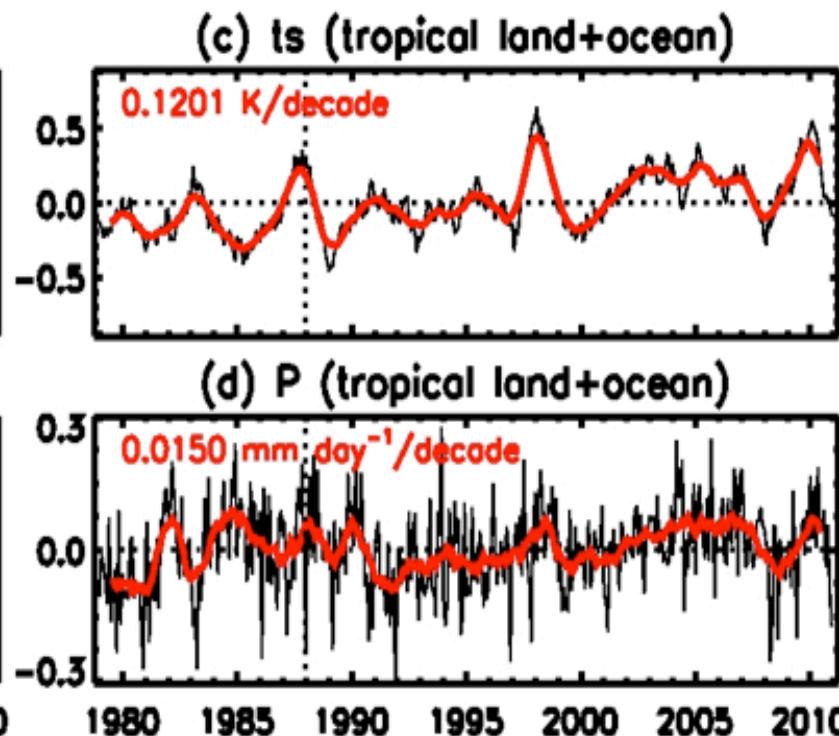
# GPCP Monthly Extended Through 2010

*Compared with Surface Temperature Analysis*

**Global**



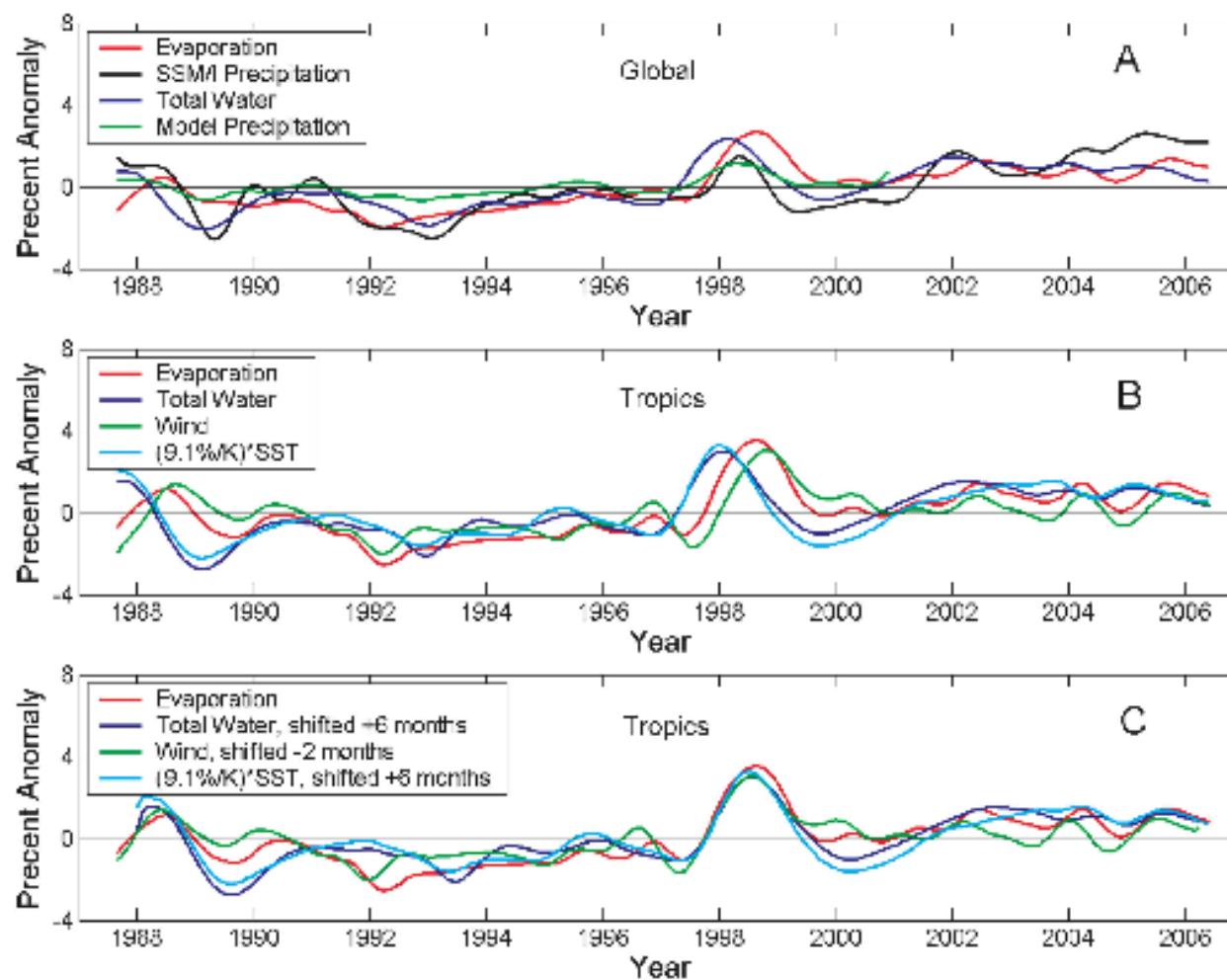
**Tropical**

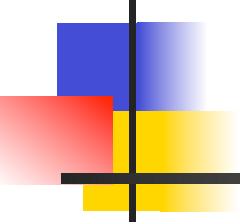


+0.05%/decade

+0.5%/decade

# RSS Precipitation (Total Water) Trends





# *Satellite Sensor/Retrieval Methods*

## Single Sensor Approaches

- *Rain gauges*
- *Infrared (GPI/OLR)*
- *Microwave Sounding Radiometers (MSU)*
- *Microwave Window Radiometers*
- *SSM/I → TMI → AMSR → WindSat → SSMIS → MWRI → MADRAS → GMI*
- *Precipitation Radar (TRMM) → DPR (GPM)*

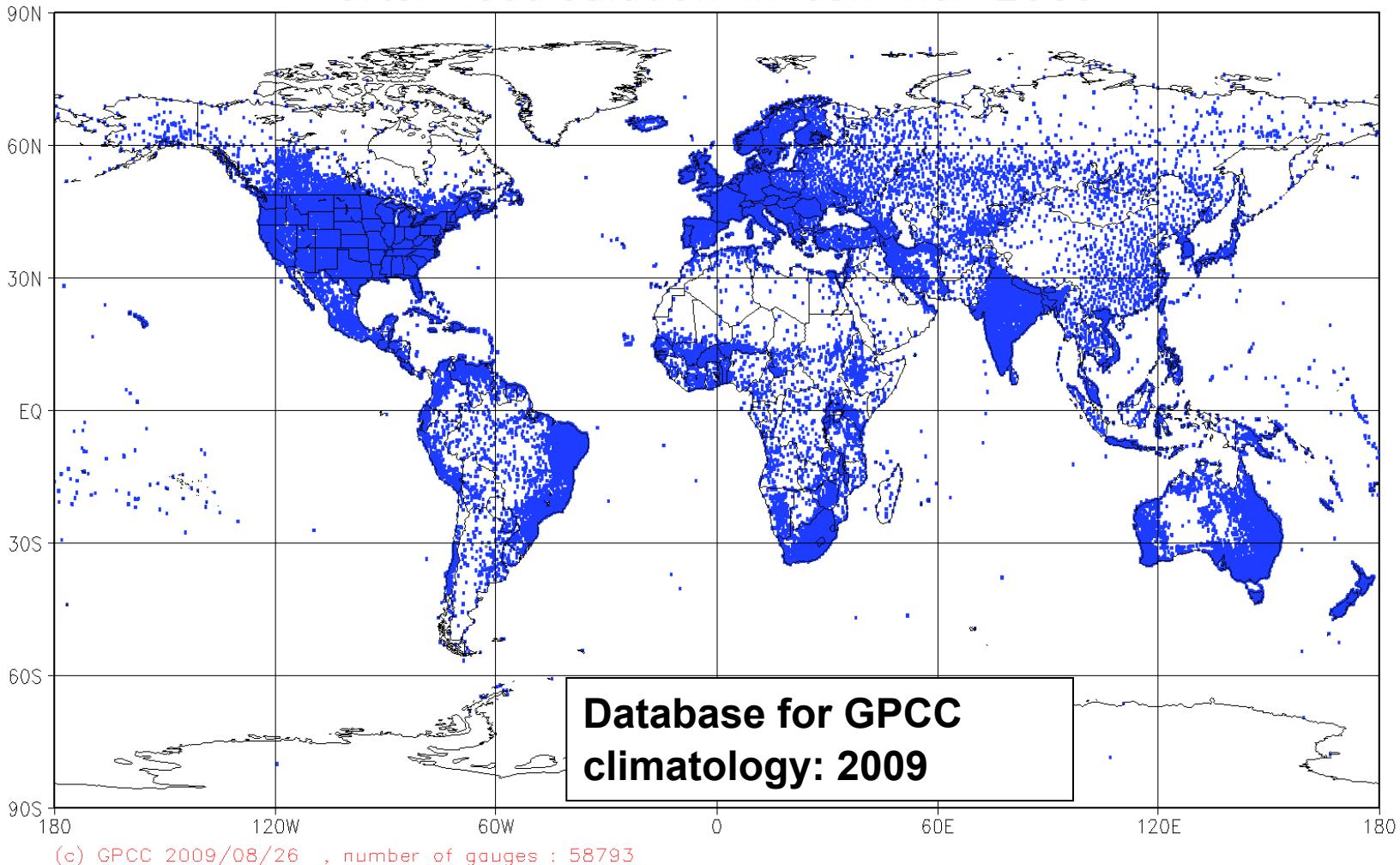
## Merged (Multi-platform) Approaches

- *Weather: TMPA, CMORPH, GSMAP, PERSIANN, GPM (3hr product)*
- *Climate: GPCP, CMAP*

## Multi-Sensor Approaches

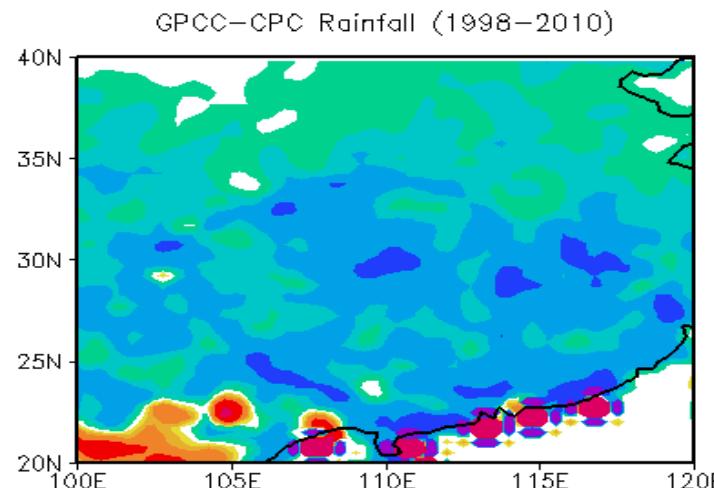
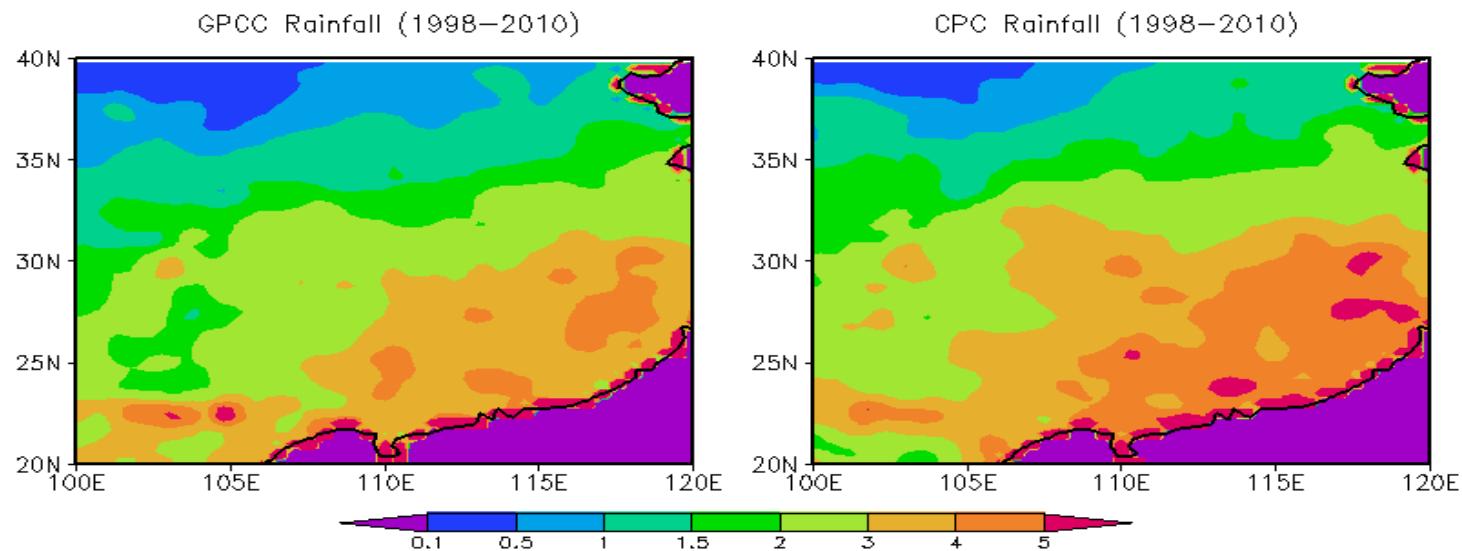
- *TRMM Radar/Radiometer*
- *GPM DPR/GMI*
- *CloudSat/MODIS/AMSR-E (In development for light rain)*

# GPCC Climatological data base



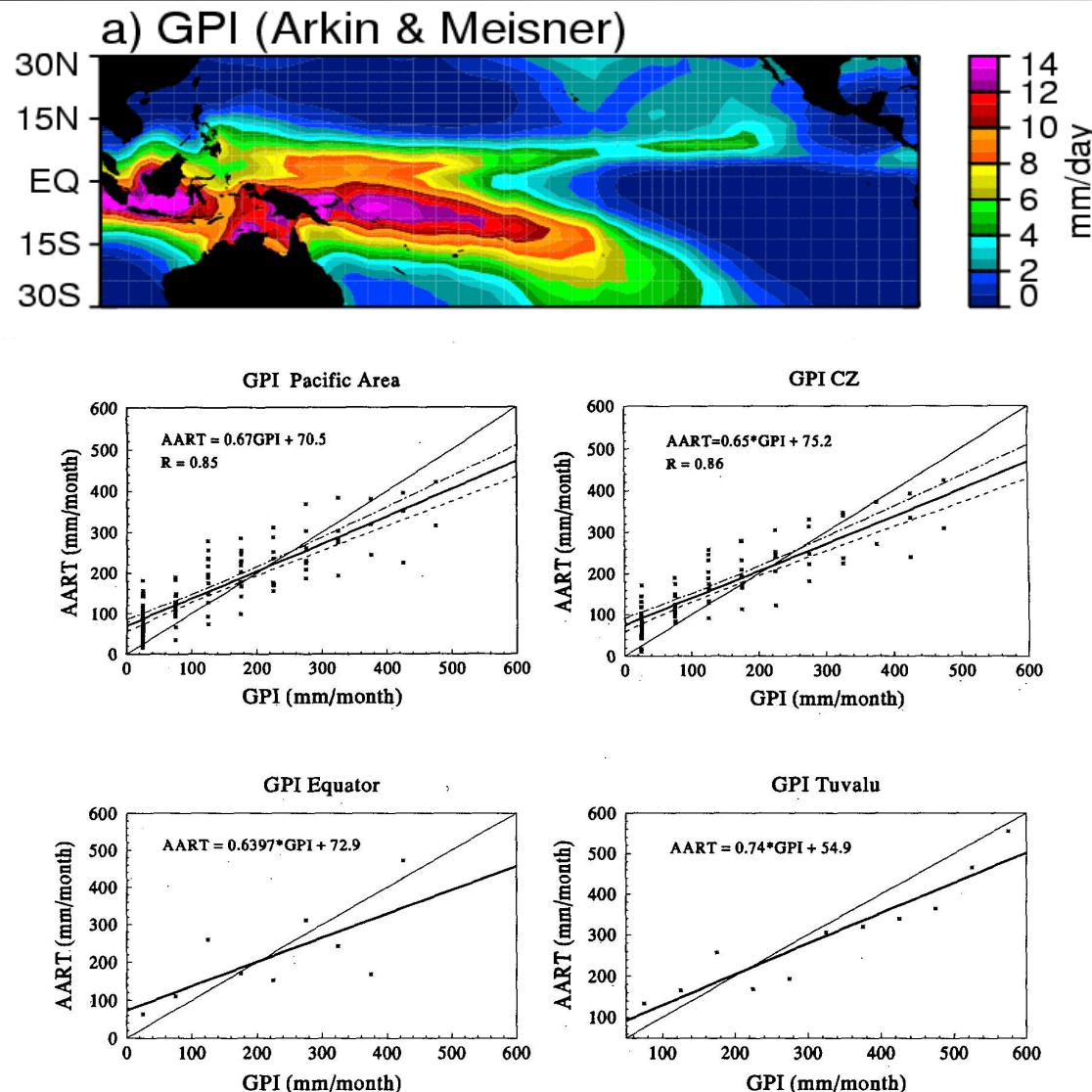
Monthly in-situ precipitation stations at GPCC as basis for anomaly analyses (Number of stations: ca. 58,500)

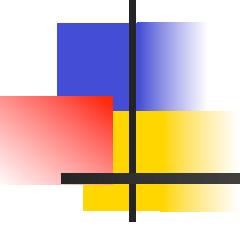
# 20% Mean Precipitation Difference Over China From Two Gauge Analyses



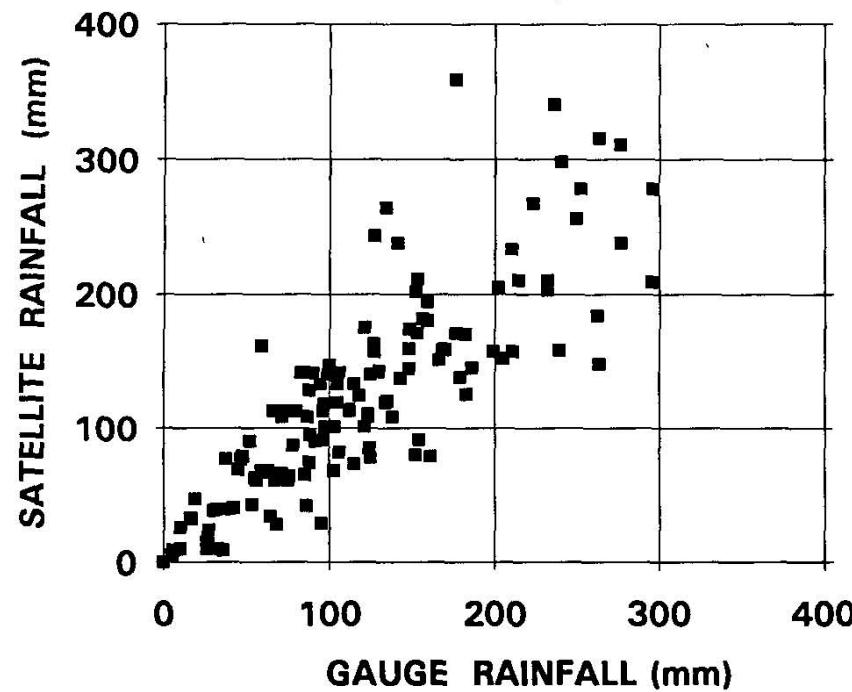
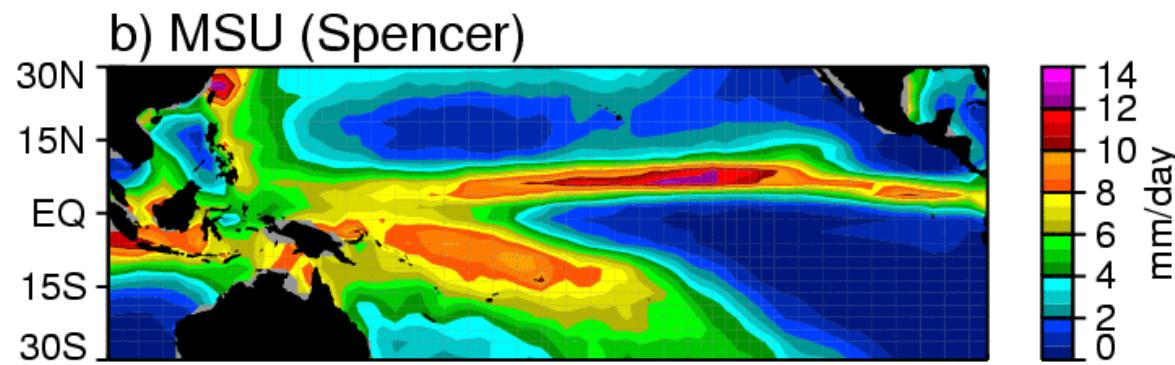
Deficiency detected in GPCC analyses by B. Adler and J.J. Wang (UMD). Attributed to differences in gauge collection used by two centers.

# Satellite Infrared - GPI

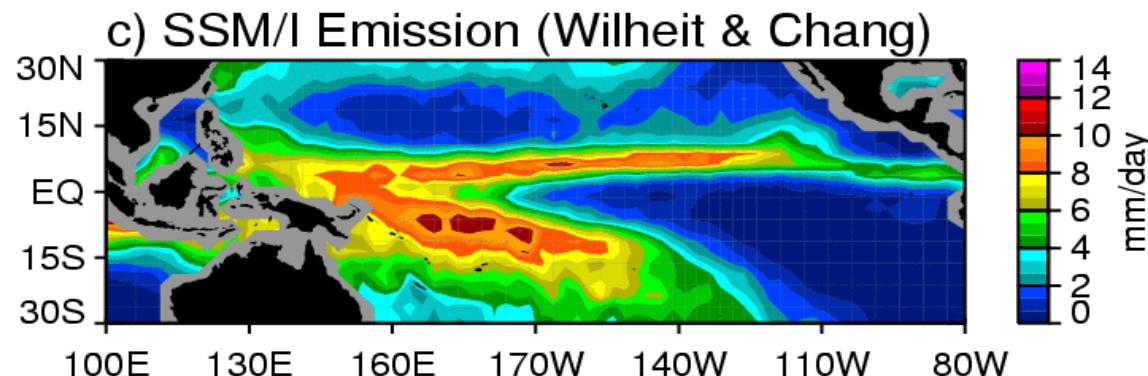




# *Satellite Microwave Sounders - MSU*

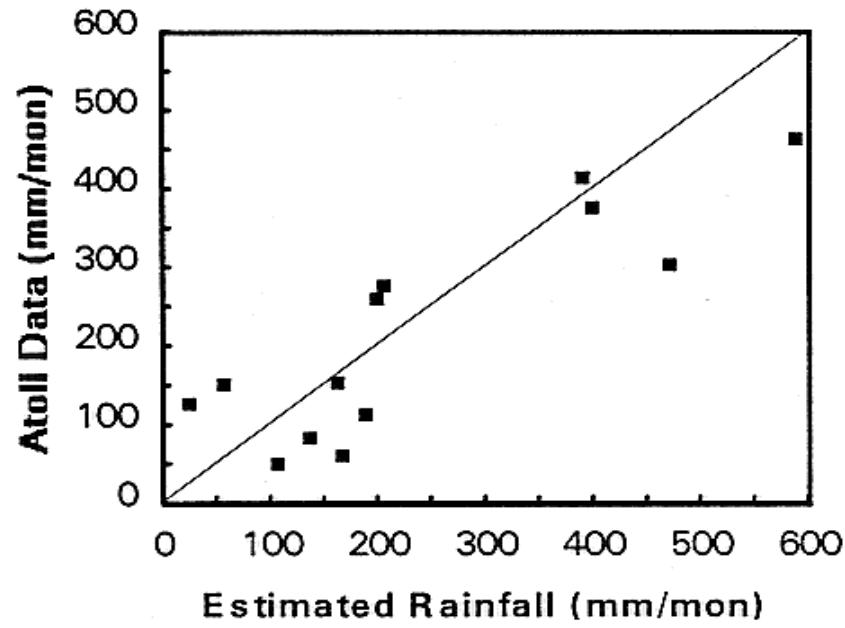
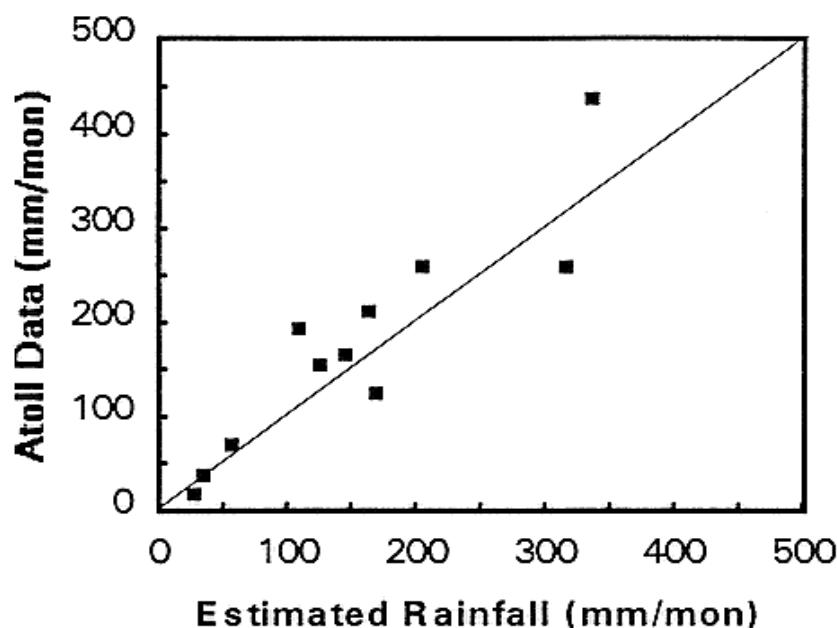


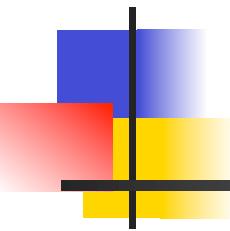
# Satellite Microwave Imagers - SSM/I



Sept. 1987

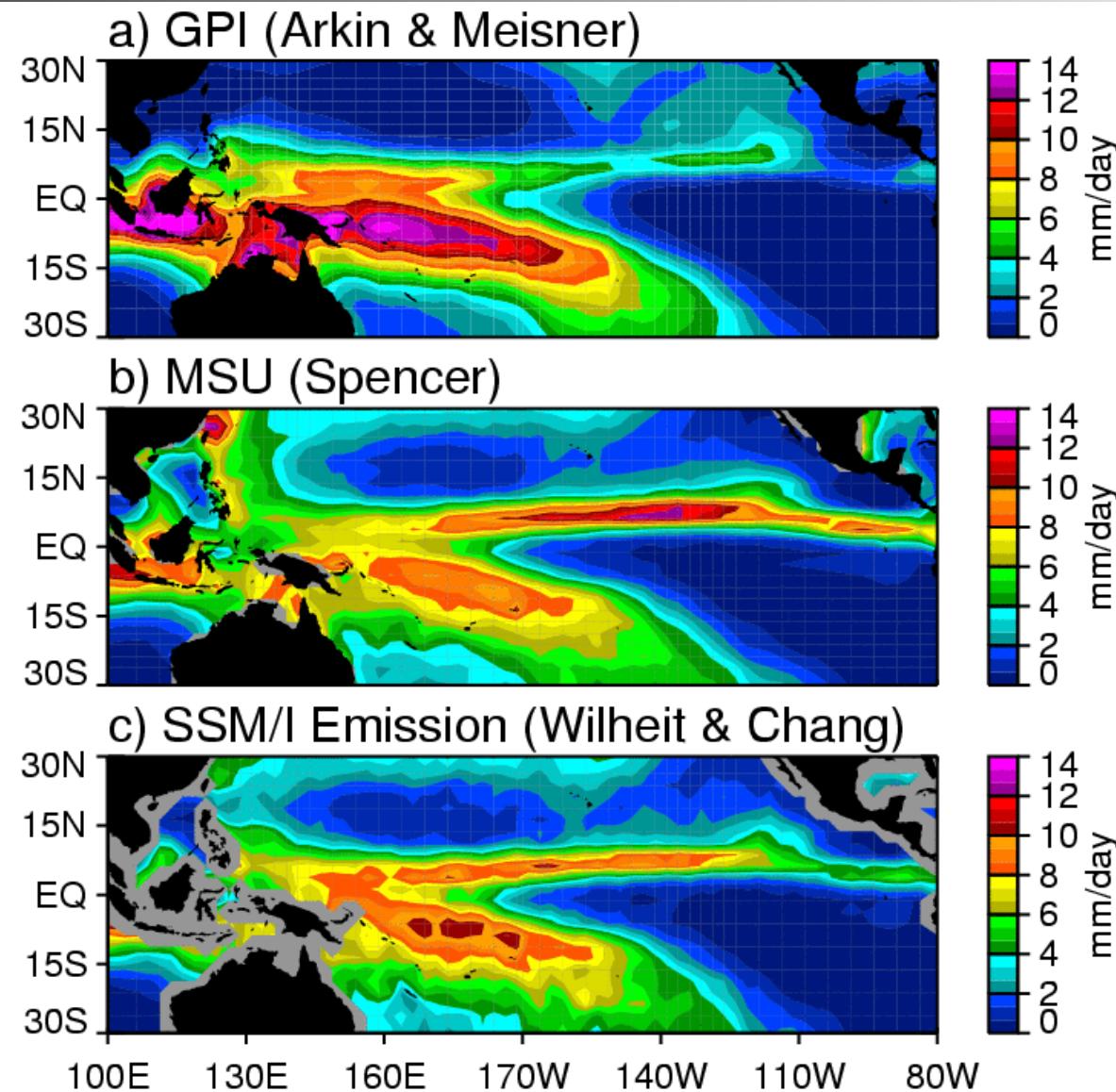
JAS, 1987



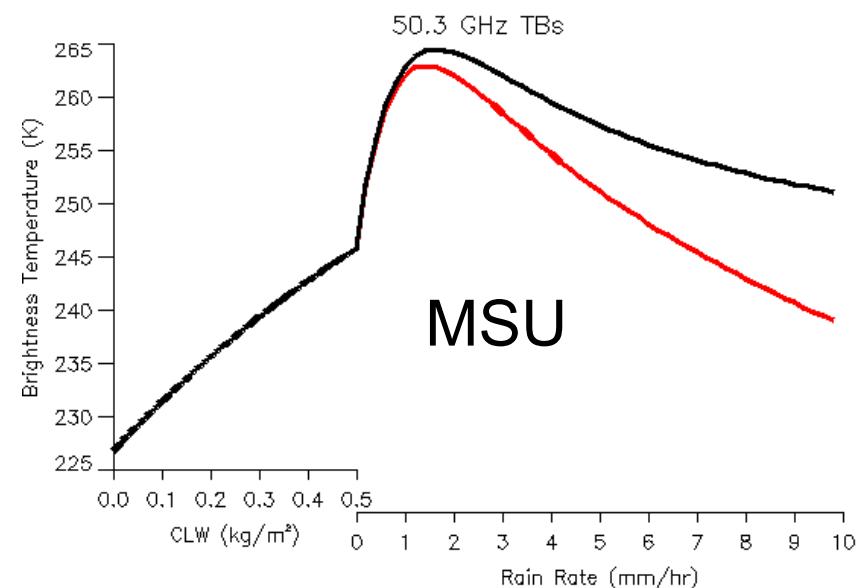
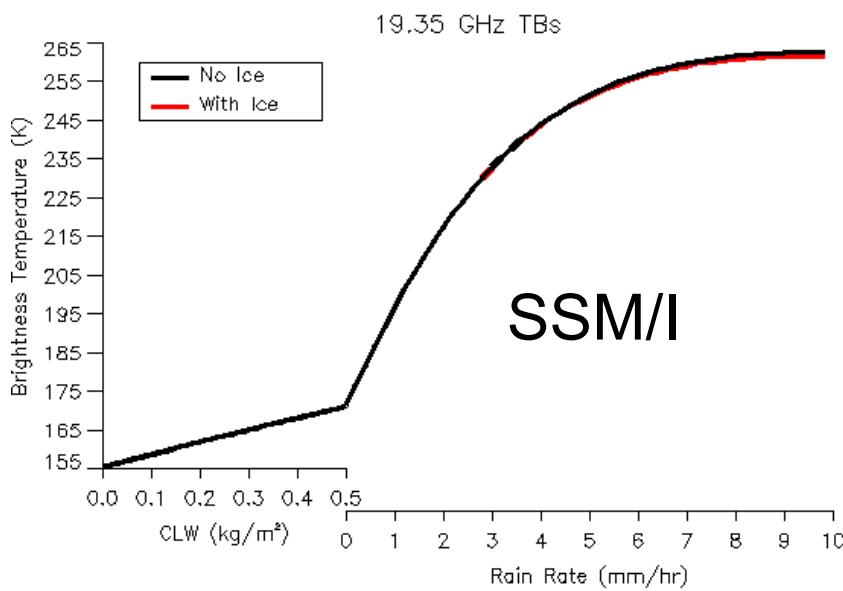
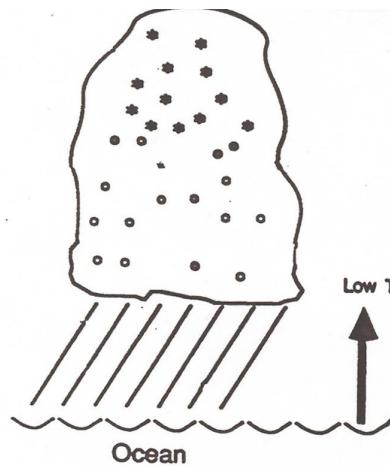


# *Satellite Rainfall Biases*

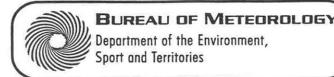
*Mean DJF Rainfall (1987 – 1996)*



# Relationship between $T_b$ and Rainfall



# Microwave or IR?



**BMRC**

# Bureau of Meteorology Research Centre

# BMRC Research Report No. 55

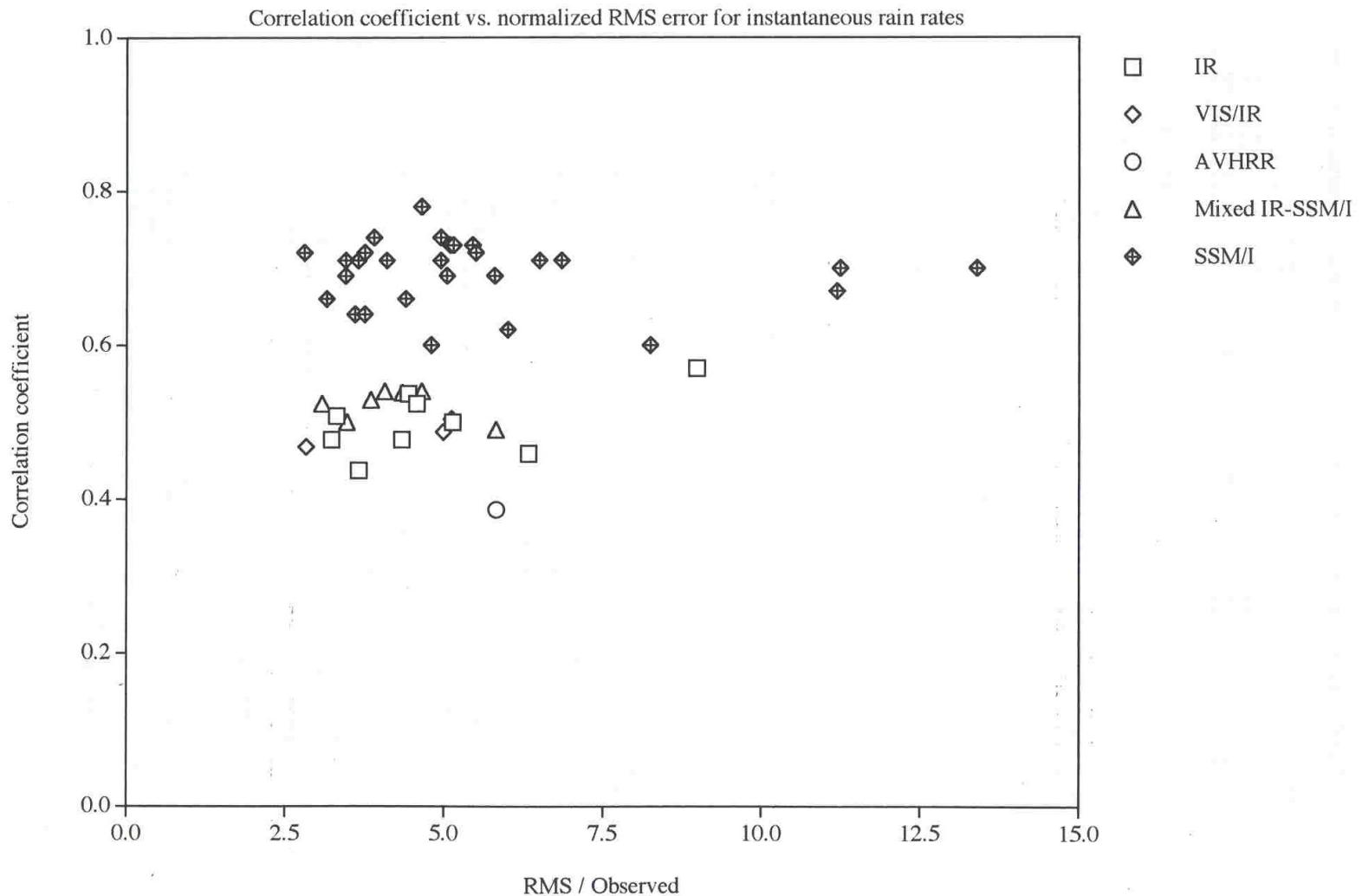
## **RESULTS OF THE 3RD ALGORITHM INTERCOMPARISON PROJECT (AIP-3) OF THE GLOBAL PRECIPITATION CLIMATOLOGY PROJECT (GPCP)**

Elizabeth E. Ebert

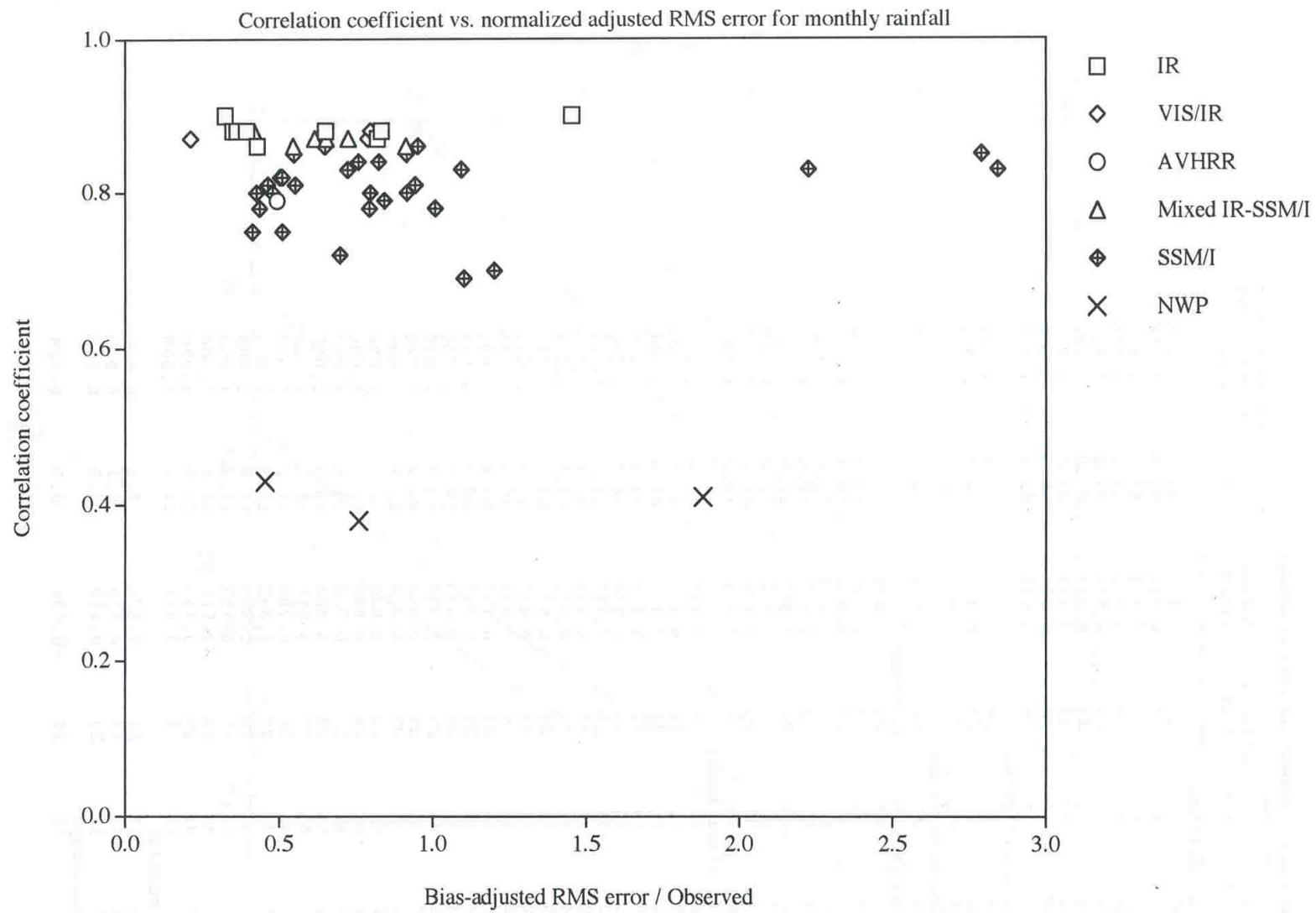
MAY 1996

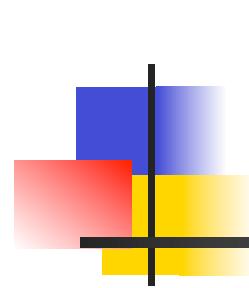
**BMRC**  
**GPO Box 1289K**  
**Melbourne**  
**Victoria**  
**Australia 3001**

# Results of IR vs Microwave (instantaneous)



# Results of IR vs Microwave (monthly average)



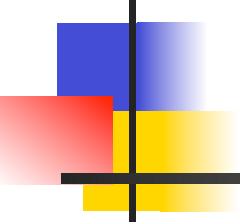


## *Interim Conclusion (1996)*

- Microwave window radiometers were better for instantaneous rain but poor sampling limited skill in monthly rainfall accumulations.
- IR estimates, while not as skilled at instantaneous rain, fared better in accumulations because of better sampling.
- NWP products lagged significantly behind observations in the tropics.

Two broad notions emerged

- It should be possible to combine microwave calibration with IR sampling might lead to improved estimates at all scales. A number of these (e.g. TMPA, CMORPH, PERSIANN would emerge in the next 5 years)
- It should be possible to use differences between sensors to understand the underlying physics of precipitation clouds.



# TMPA – Flow Chart

## TRMM Multi-satellite Precipitation Analysis

Computed in both real and post-real time, on a 3-hr 0.25° grid

Microwave precip:

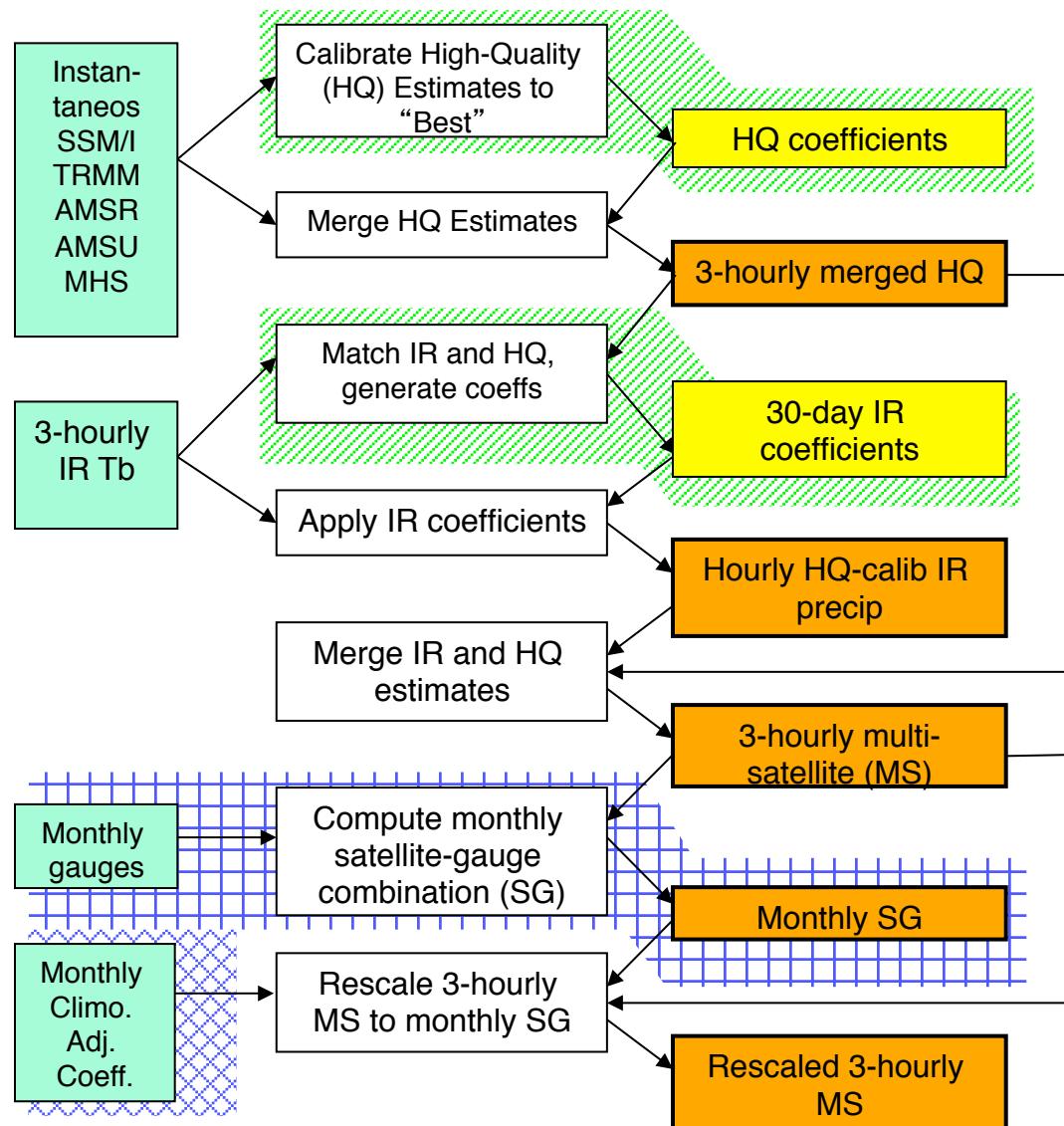
- intercalibrate to TMI/PR combination for P
- intercalibrate to TMI for RT
- then combine, conical-scan first, then sounders

IR precip:

- calibrate with microwave

Combined microwave/IR:

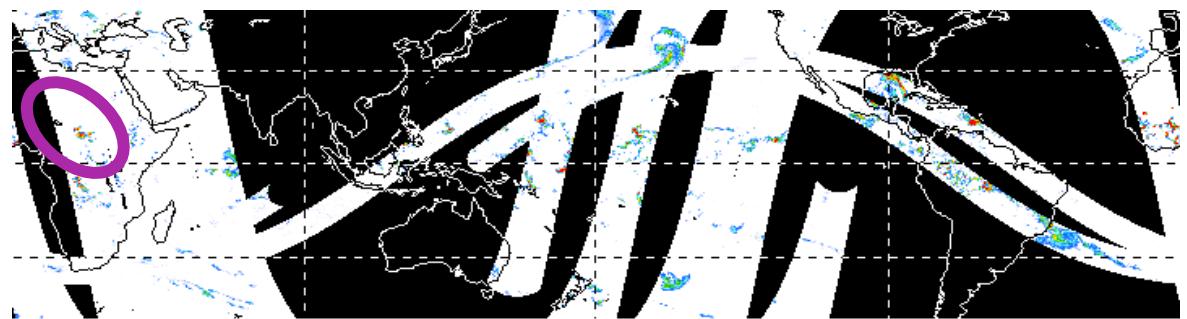
- IR fills gaps in microwave



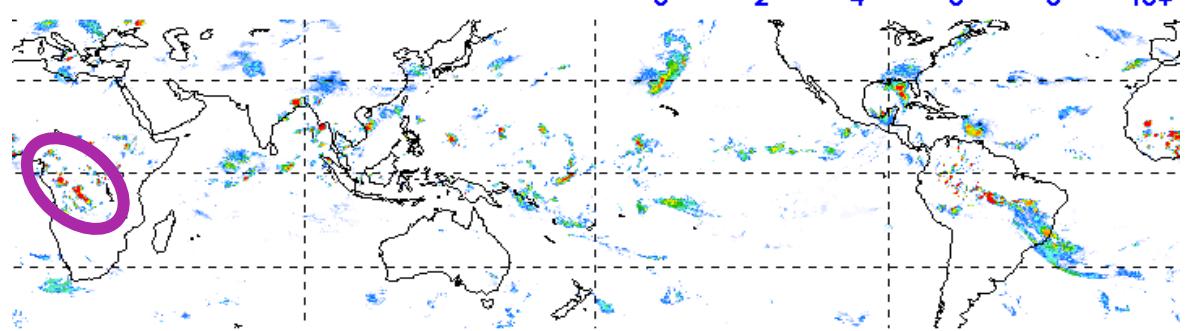
# TMPA – Example

Combined inter-calibrated microwave precip

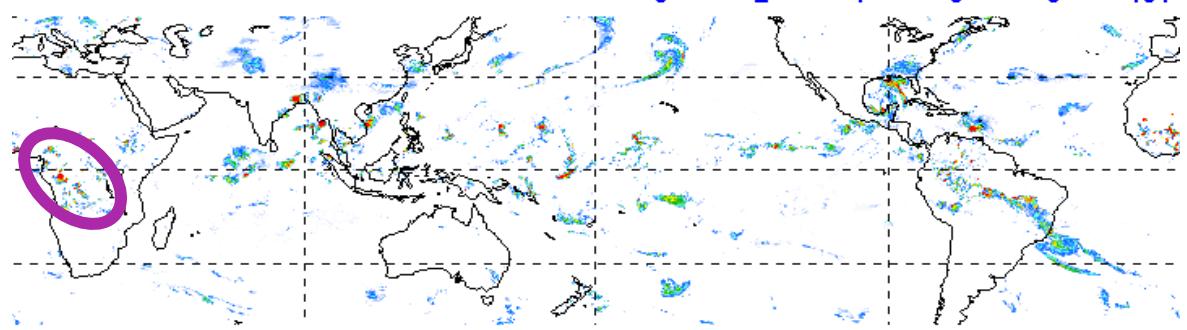
- all swaths +/-90 minutes around 18Z



HQ Merge (mm/h) 18Z 24 Sep 2002 0 2 4 6 8 10+



VAR (mm/h) 18Z 24 Sep 2002 0 2 4 6 8 10+



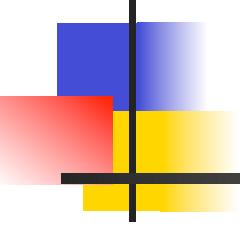
HQ+VAR Merge (mm/h) 18Z 24 Sep 2002 0 2 4 6 8 10+

Microwave-calibrated geo-IR precip

- image at 18Z

Merged microwave and geo-IR precip

- IR fills holes in the microwave field
- NW storm in Africa is IR; SW is microwave



# TMPA – Dominant Controls on Performance

Monthly (and longer) bias in amount

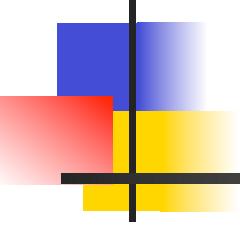
- land: rain gauge analysis
- ocean: calibrating satellite estimator

Fine-scale variations

- land and ocean: occurrence of precipitation in the individual input datasets
- inter-satellite calibration attempts to enforce consistency in distribution
- event-driven statistics depend on satellites, e.g. bias in frequency of occurrence

Differences between sensors tend to be visible

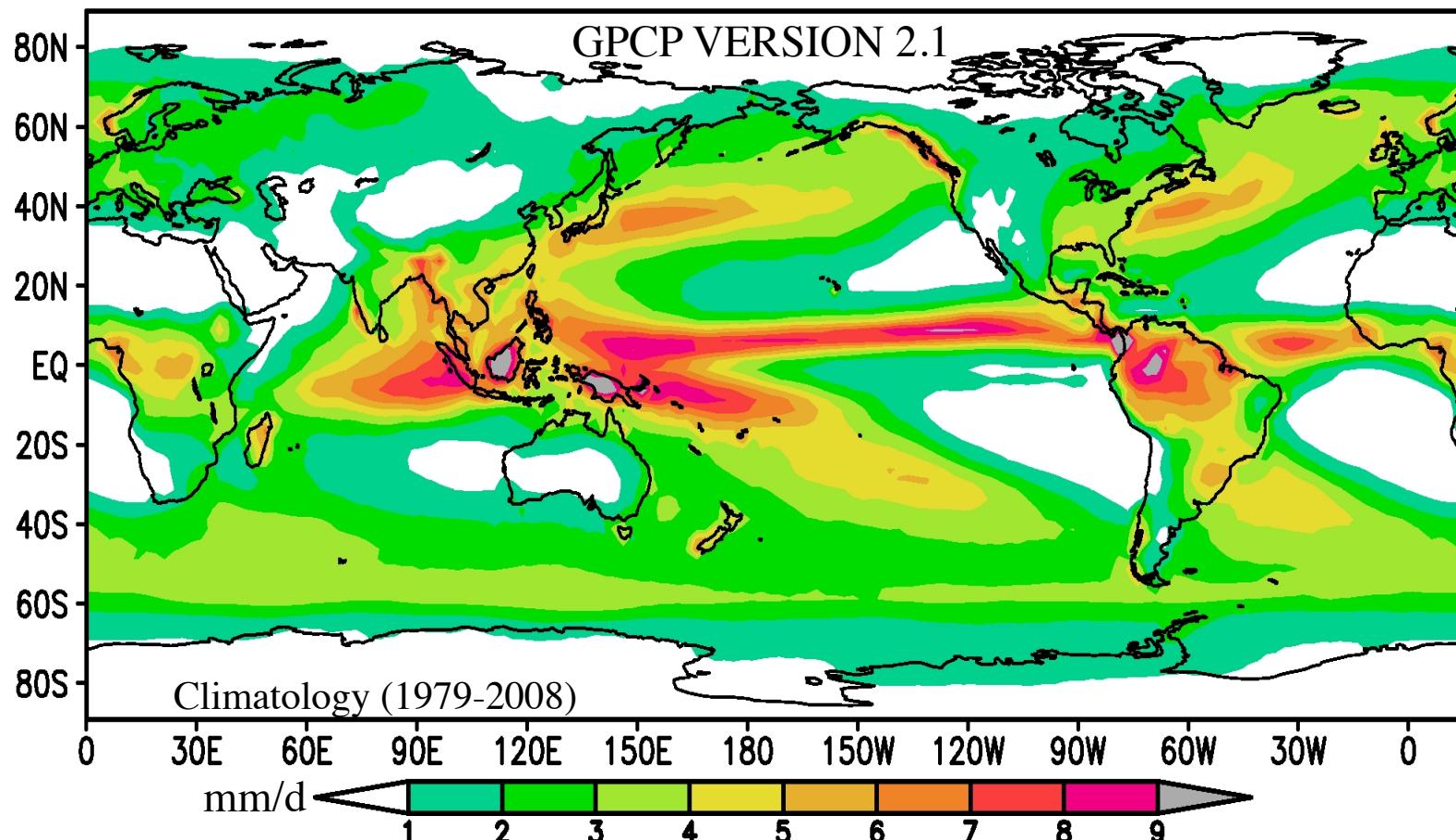
- different sensors “see” different aspects of the same scene
- limited opportunities to “fix” problems with the individual inputs
- satellite sensors tend to be best for tropical ocean
- satellite sensors and rain gauge analyses tend to have more trouble in cold, complex terrain



## *Interim Conclusion (Circa 2005)*

- More microwave satellites improved sampling but user needs increased correspondingly from monthly, large scale precipitation to scales down to daily,  $0.25^\circ$  products
- Merged techniques differ but all used passive microwave to **calibrate** IR (at different space time scales) and then use the calibrated IR or merge the microwave and calibrated IR estimates
- Climate sensitivity is almost completely determined by gauges over land and passive microwave estimates over ocean.

# Global Precipitation Climatology Project (GPCP)

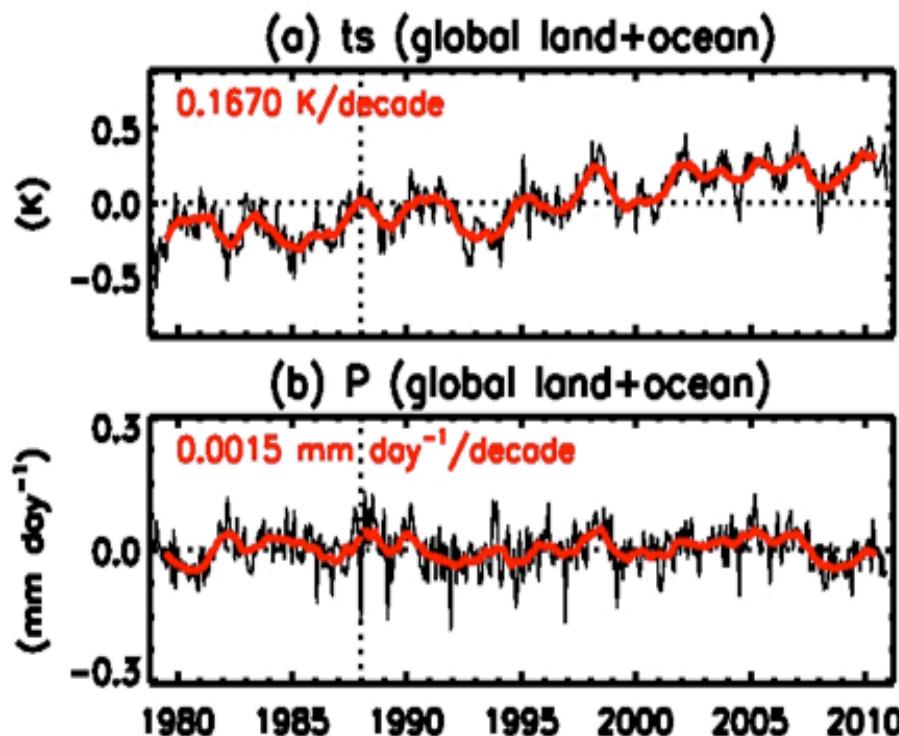


Robert Adler (GPCP Coordinator)  
U. of Maryland-College Park, USA

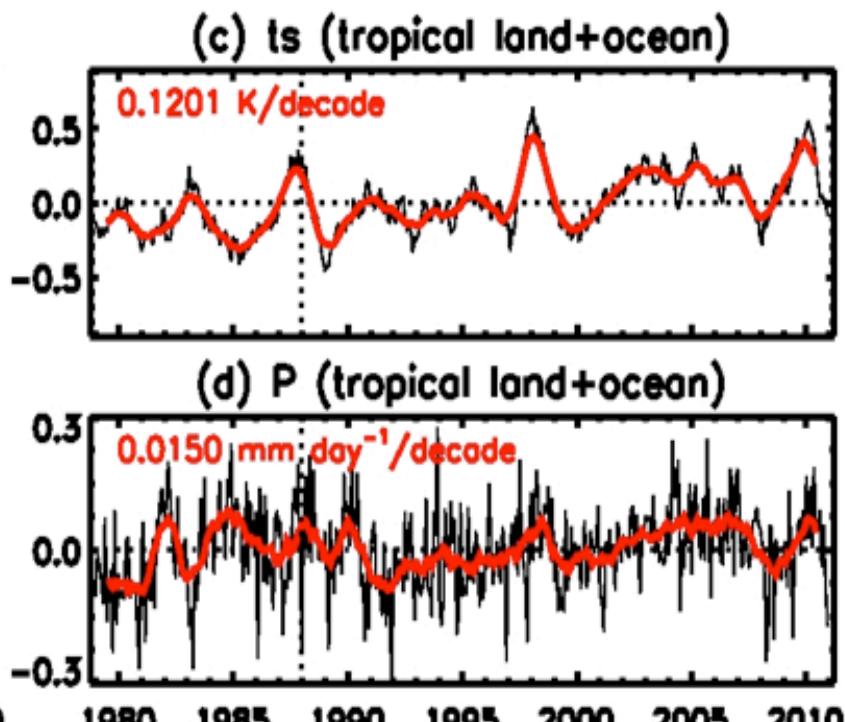
# GPCP Monthly Extended Through 2010

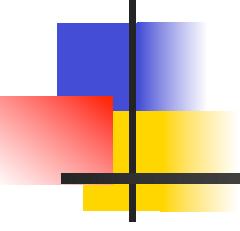
*Compared with Surface Temperature Analysis*

**Global**

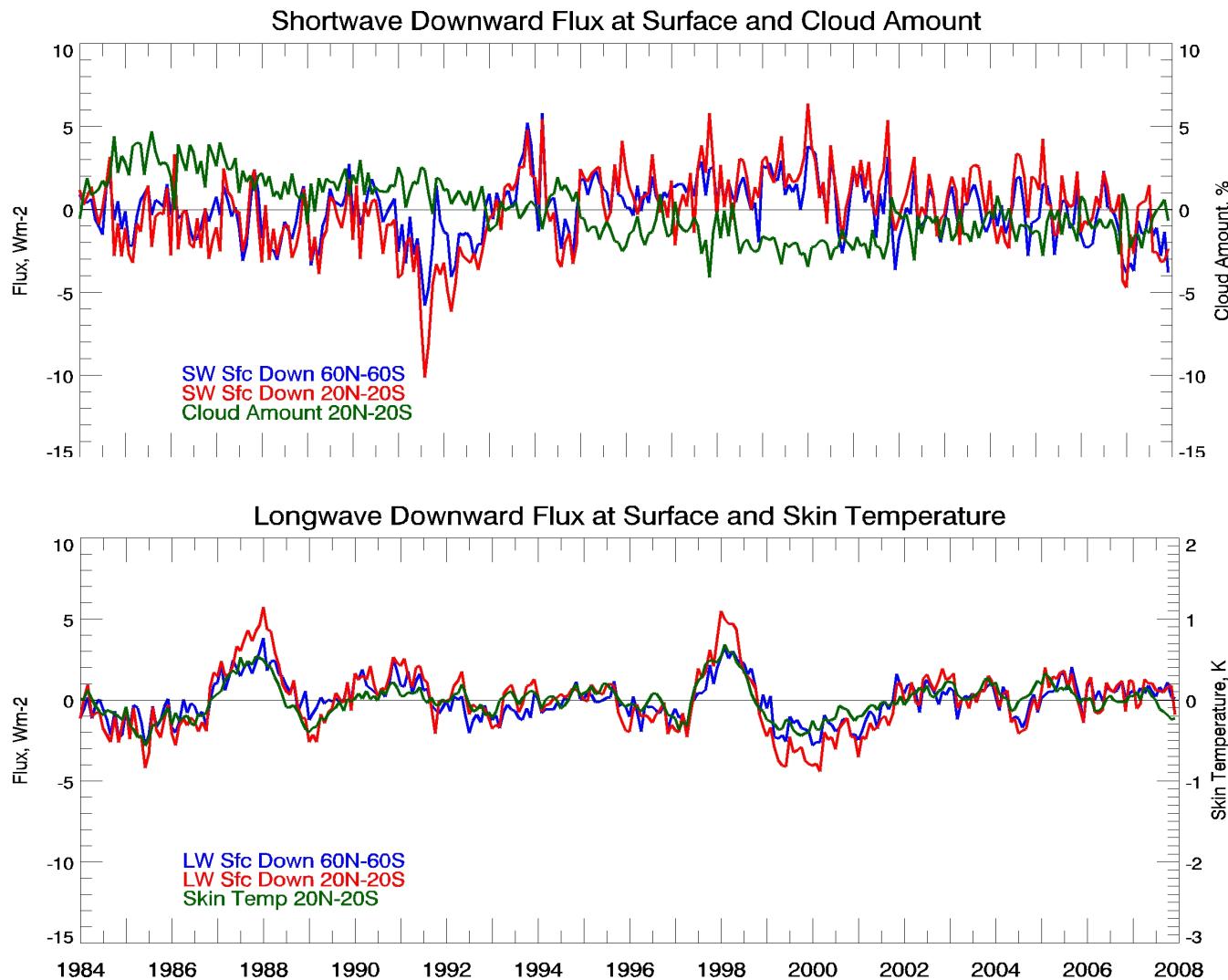


**Tropical**

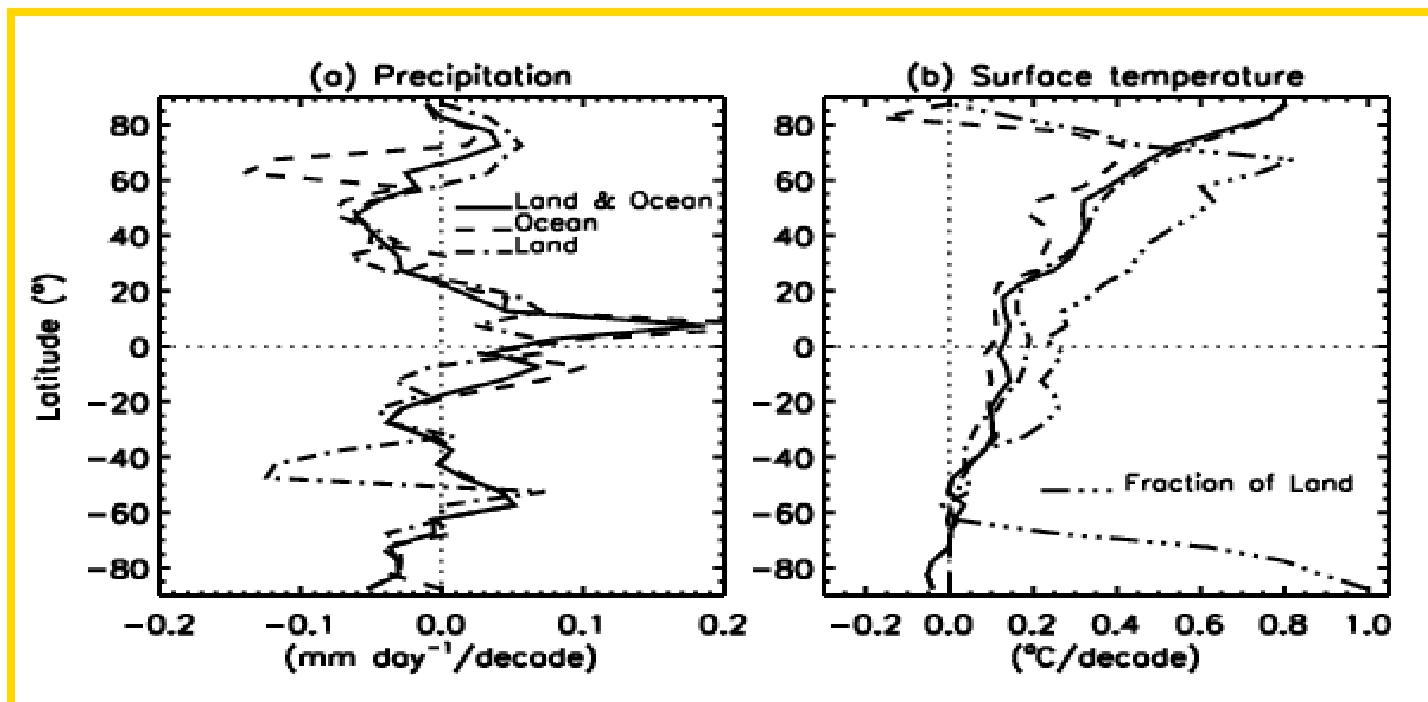
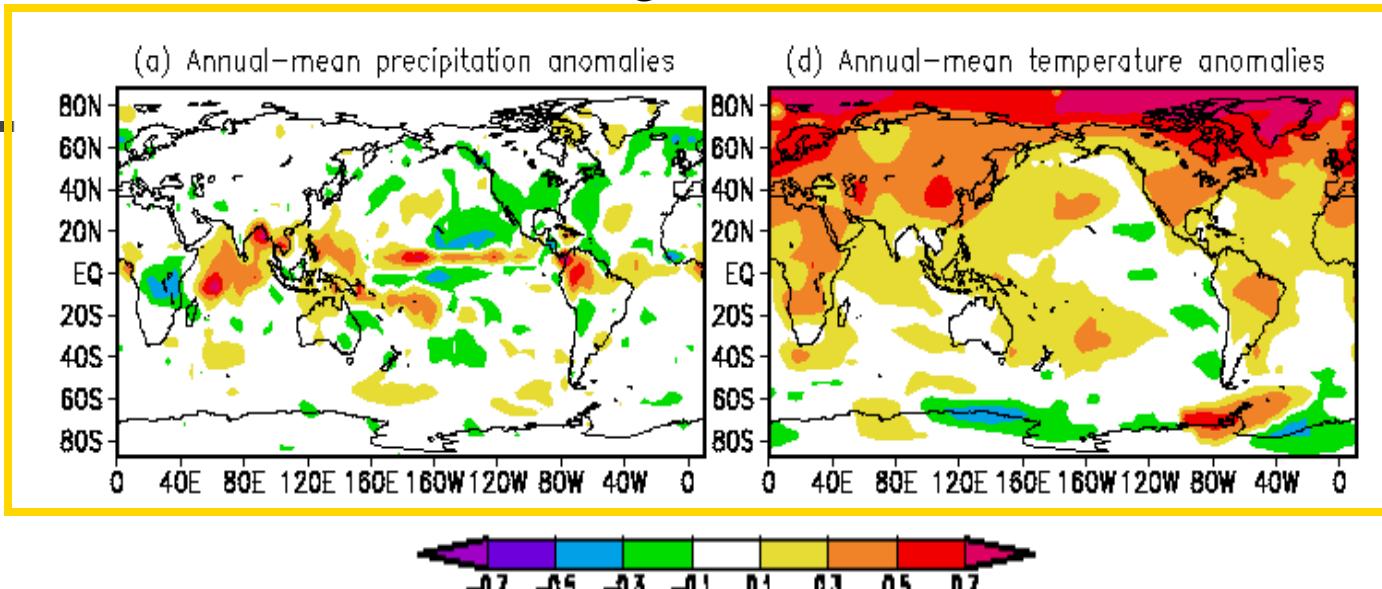


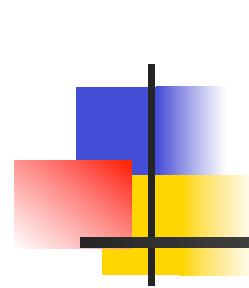


# Short- and LongWave Fluxes



# Linear Changes (1979-2006)





## *Current Understanding (2012)*

- Water budget in Central Pacific closes remarkably well. Increased rainfall due to increased water vapor convergence rather than local effects.
- Lack of trends in GPCP related to gauges over land and passive microwave over oceans. During ENSO, precipitation over land decreases to keep global mean nearly constant.
- While there is an offset between Radiation and precipitation, trends (lack thereof) are consistent among GEWEX products
- A paper from Wentz et al. showed greater sensitivity to warming. The product assumes no change in cloud properties (except for freezing height) with warmer SST.



# Tropical Rainfall Measuring Mission (TRMM)

NASDA  
NATIONAL SPACE DEVELOPMENT AGENCY OF JAPAN

## Precipitation radar (PR):

13.8 GHz  
4.3 km footprint  
0.25 km vertical res.  
215 km swath

## Microwave radiometer (TMI):

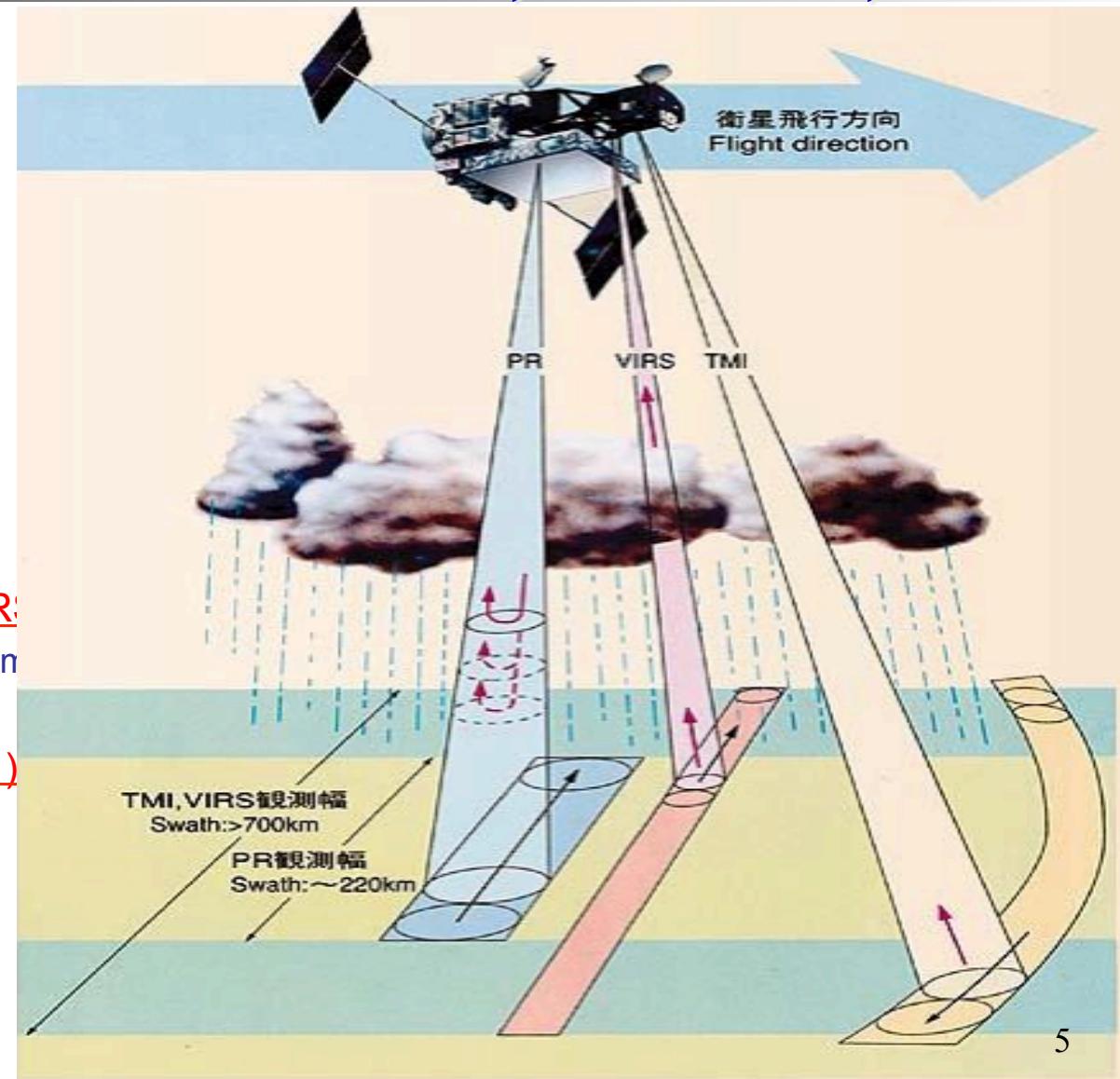
10.7, 19.3, 21.3, 37.0  
85.5 GHz (dual polarized  
except for 21.3 V-only)  
10x7 km FOV at 37 GHz  
760 km swath

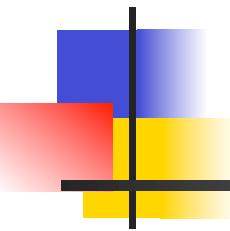
## Visible/infrared radiometer (VIRS):

0.63, 1.61, 3.75, 10.8, and 12  $\mu$ m  
at 2.2 km resolution

## Lightning Imaging Sensor (LIS)

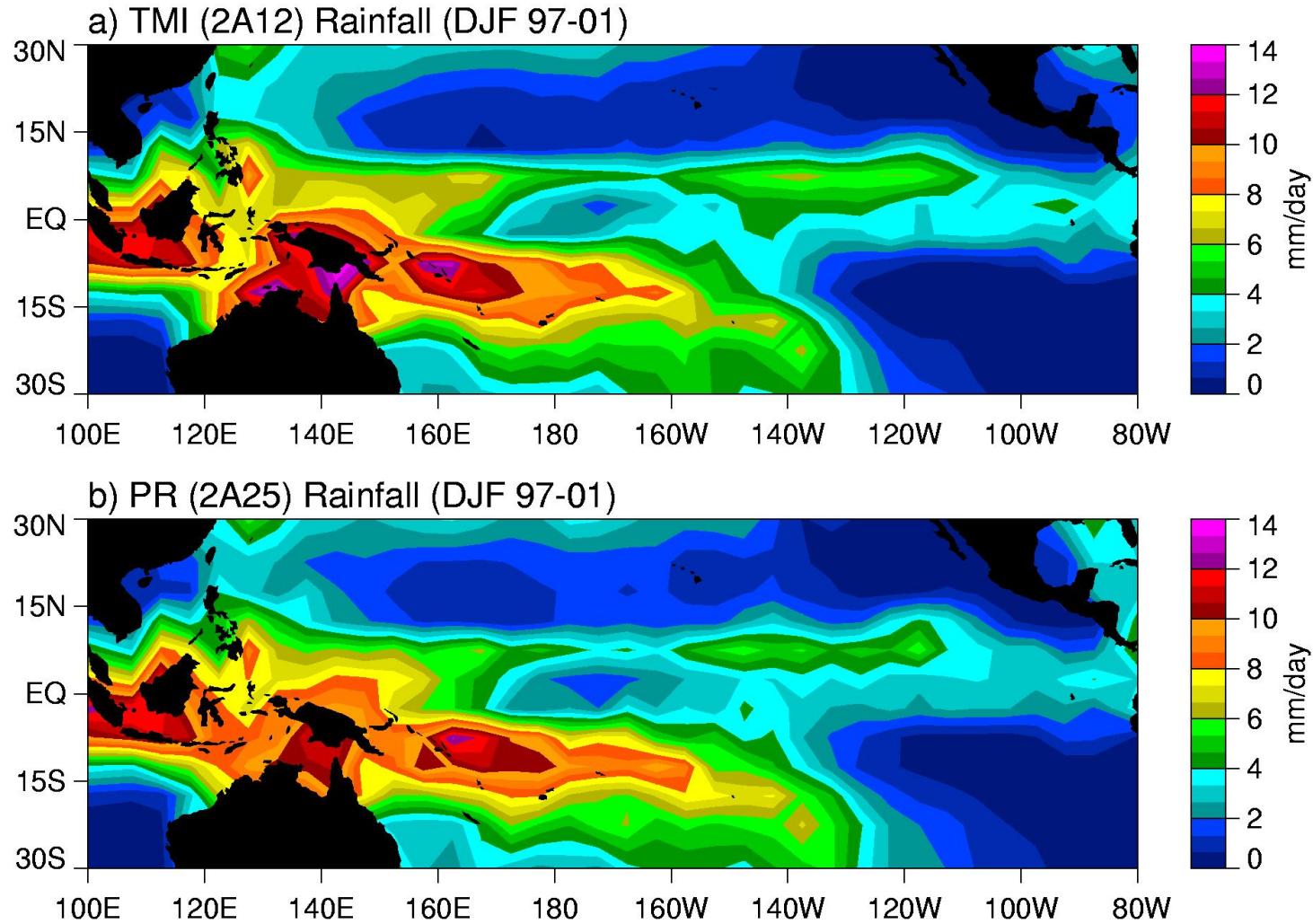
## Cloud & Earth Radiant Energy System (CERES)



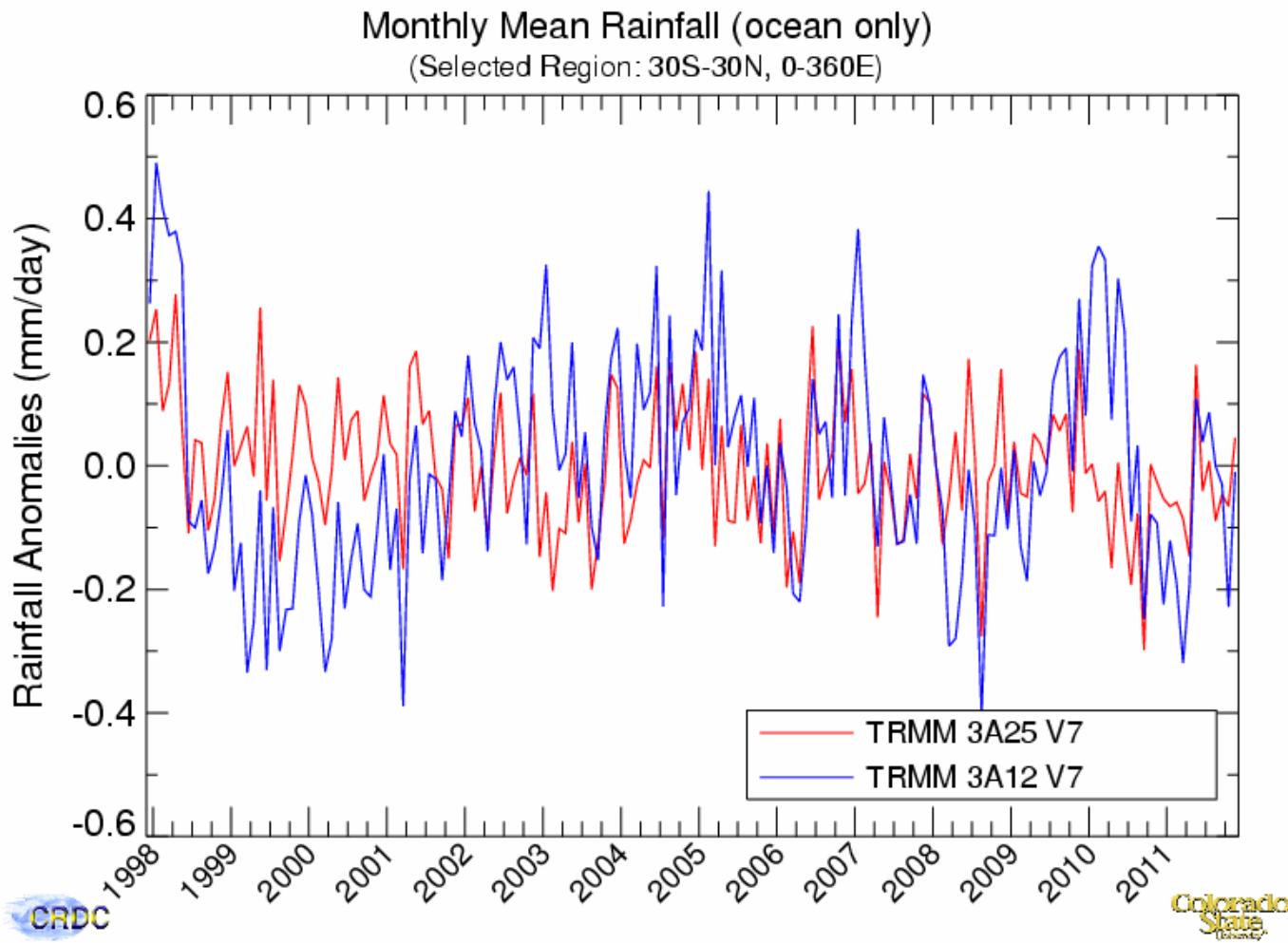


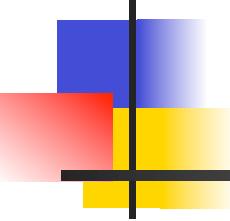
# *Mean DJF Rainfall*

*(TRMM Retrievals)*



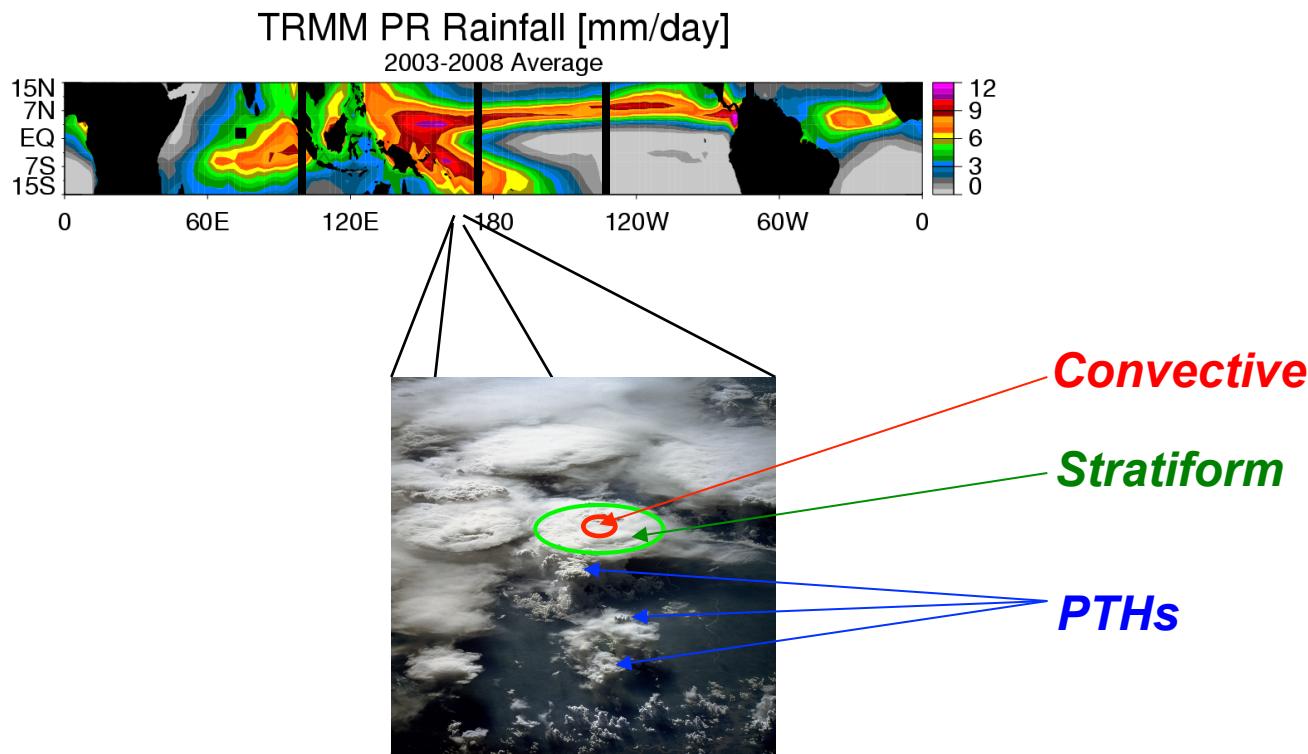
# *TRMM PR/TMI Rainfall Variability*



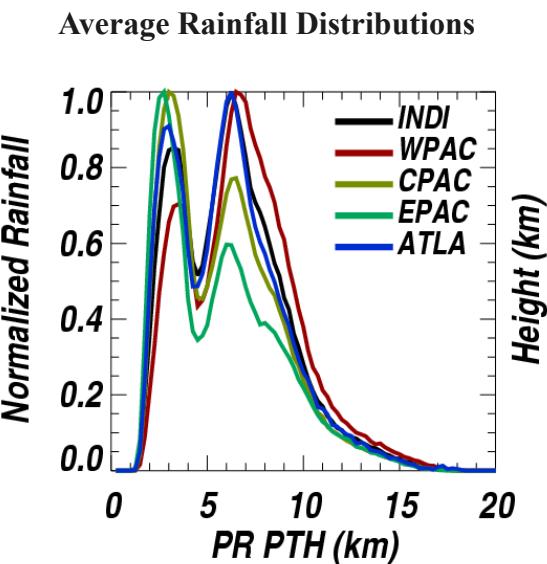
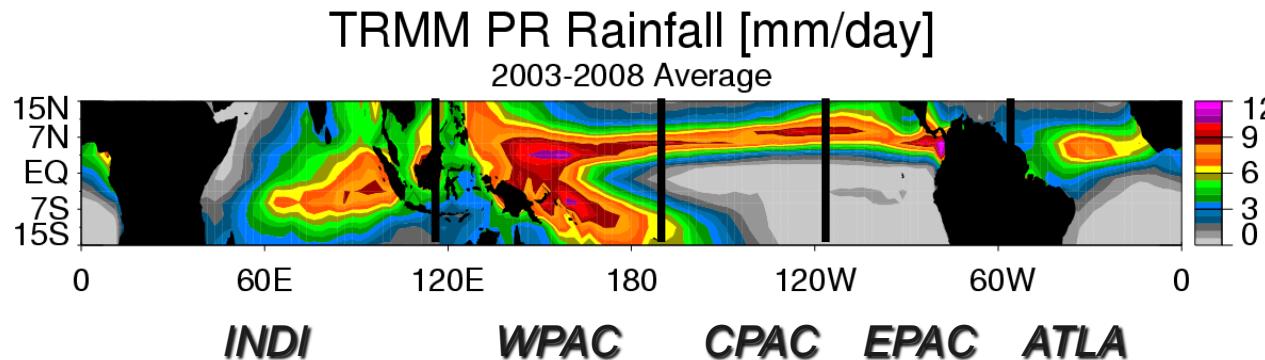


# *Cloud Structures in the Tropics.*

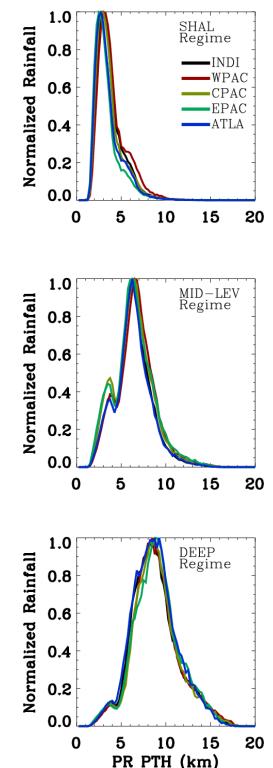
For each 100 x 100 km box in tropics, save distribution of precipitation top heights (PTHs), mean convective rainfall and ratio of convective to stratiform rainfall.

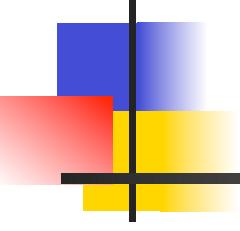


# Cloud Clusters



Apply K-means clustering  
algorithm on PTH,  
Convective rain and C/S fraction

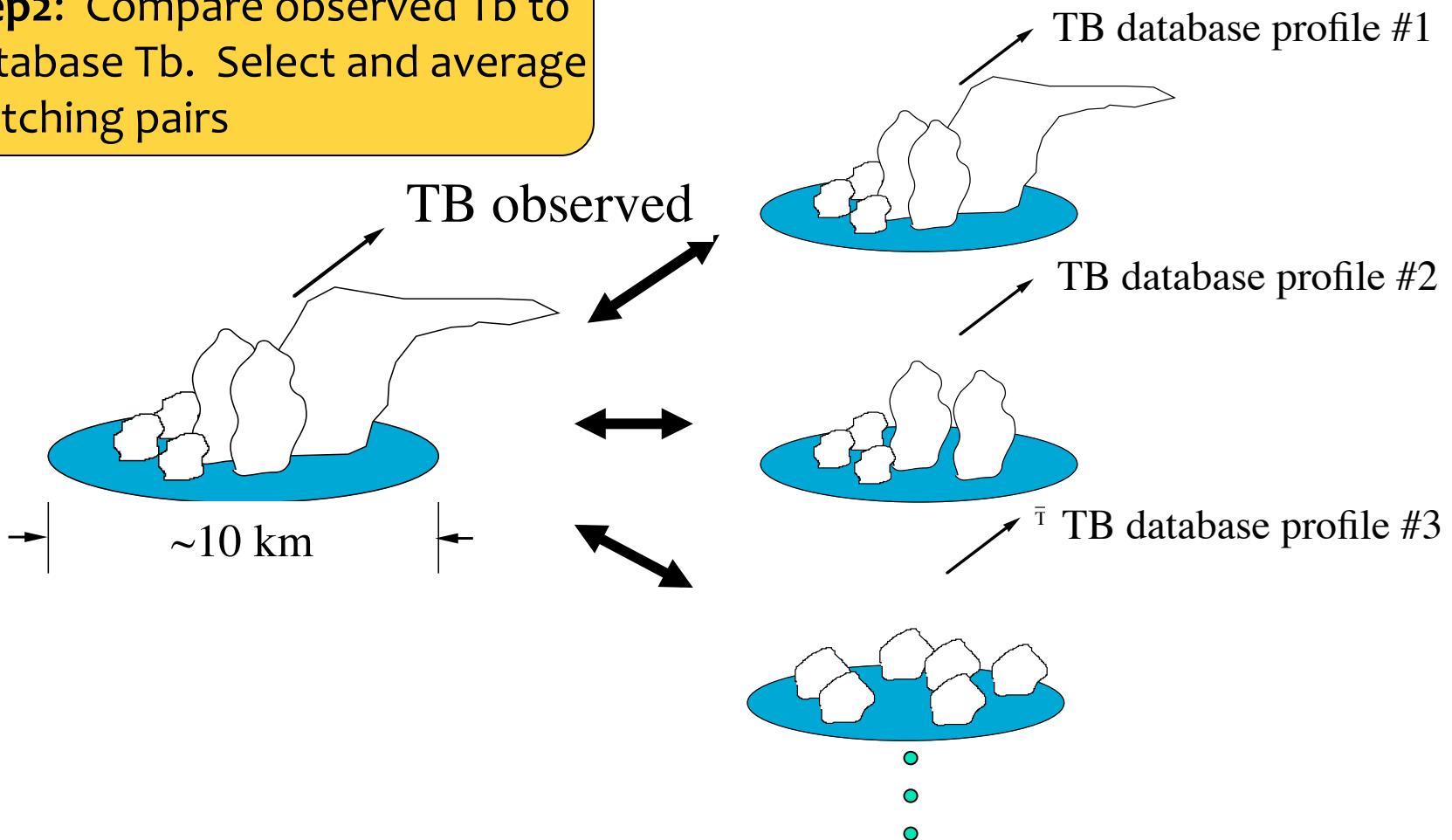


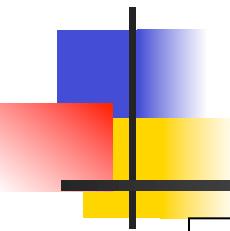


# The GPM radiometer algorithm

**Step 1:** Use TRMM/GPM Satellite to derive set of “**Observed**” profiles that define an a-priori database of possible rain structures.

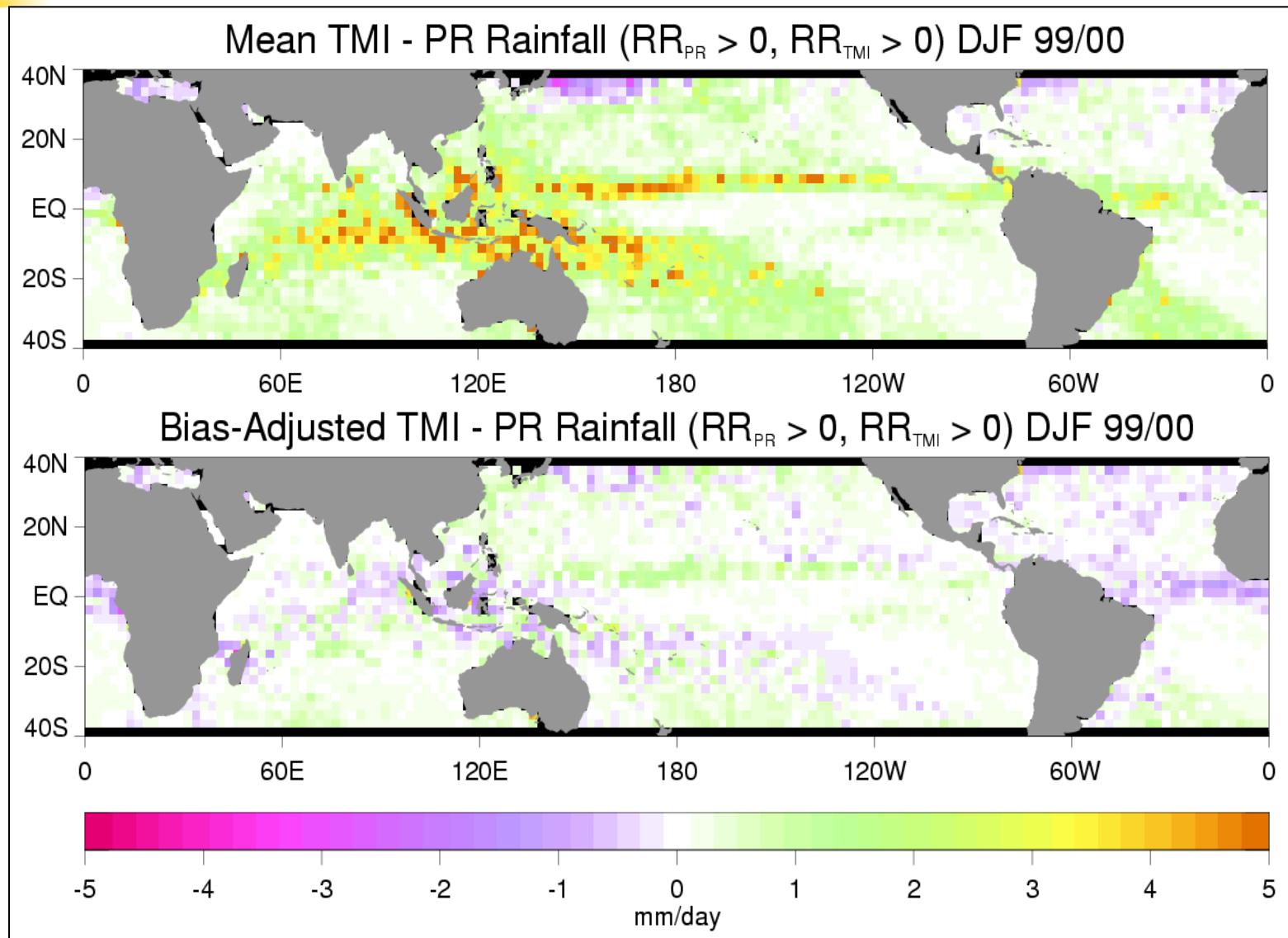
**Step 2:** Compare observed Tb to Database Tb. Select and average matching pairs



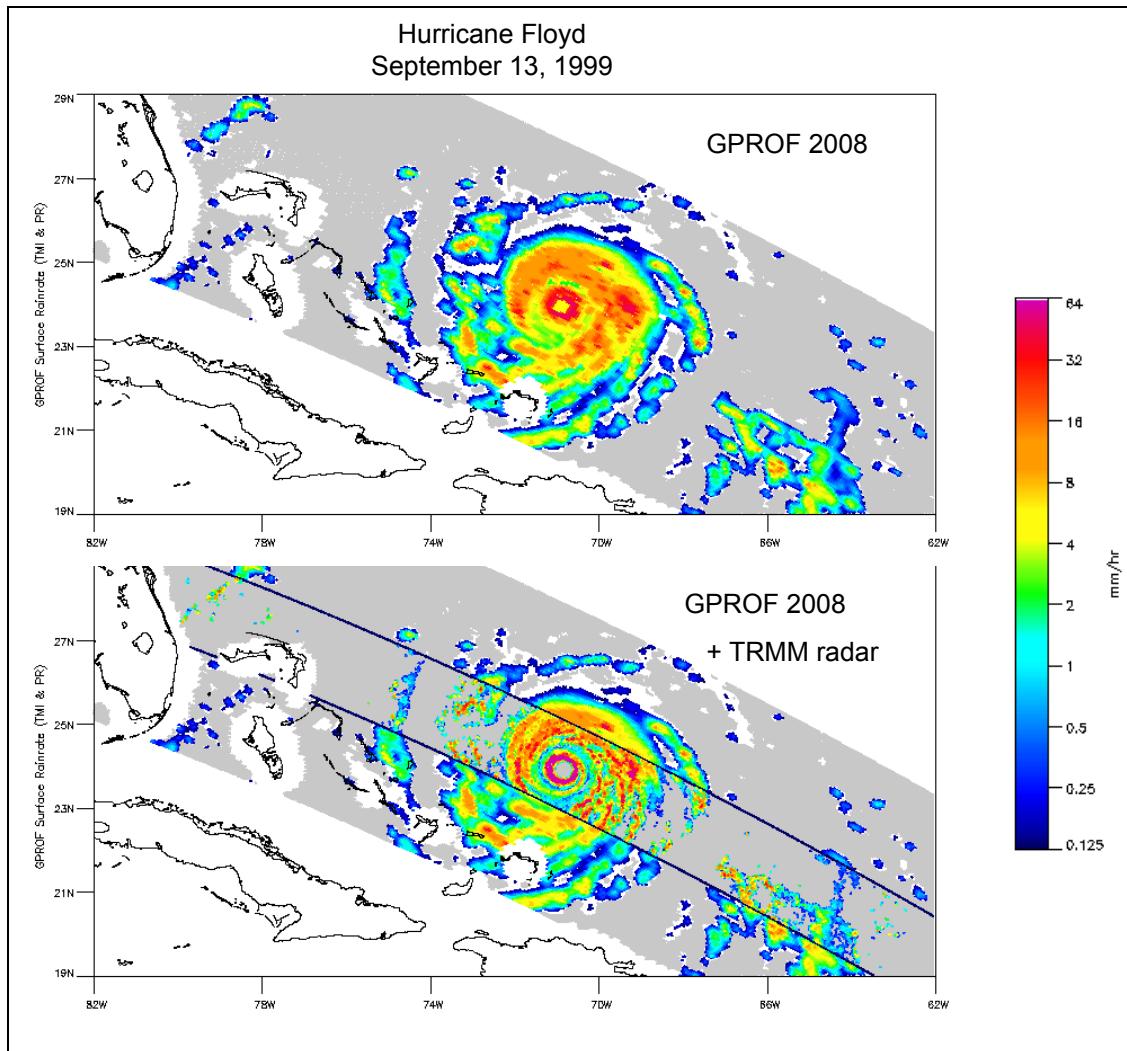


# Rainfall Bias Removal

Based on Column Water Vapor

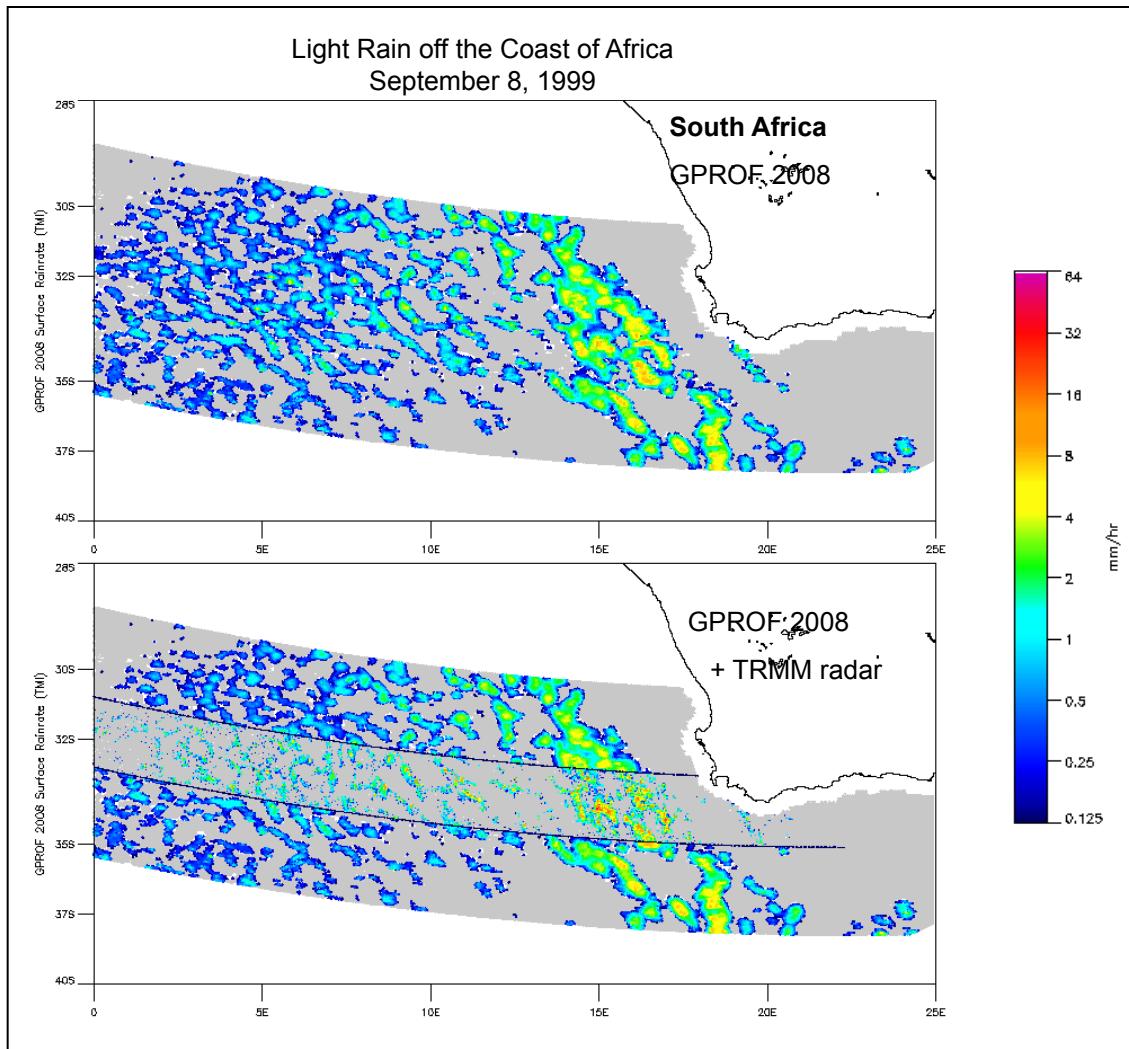


# Parametric GPROF Results (ocean)



Bayesian scheme used to retrieve rainfall (TMI only). Database sorted by SST and TPW

# Parametric GPROF Results (ocean)



Bayesian scheme used to  
retrieve rainfall (TMI only).  
Database sorted by SST  
and TPW

# GPROF algorithm and ECMWF 1D+4D-Var

Under-constraint retrievals given the observations.

Bayesian formulation:

$$Pr(x | y) = \frac{Pr(y | x) Pr(x)}{Pr(y)}$$

Goddard PROFiling algorithm (GPROF):

$$\hat{E}(\mathbf{x}) = \sum_i \mathbf{x}_i \exp \left\{ -0.5 [\mathbf{y} - H(\mathbf{x}_i)]^T (\mathbf{O} + \mathbf{S})^{-1} [\mathbf{y} - H(\mathbf{x}_i)] \right\}$$

*microphysics profiles*      *weighting*

ECMWF one-dimensional + four-dimensional variational analysis (1D+4D-Var):

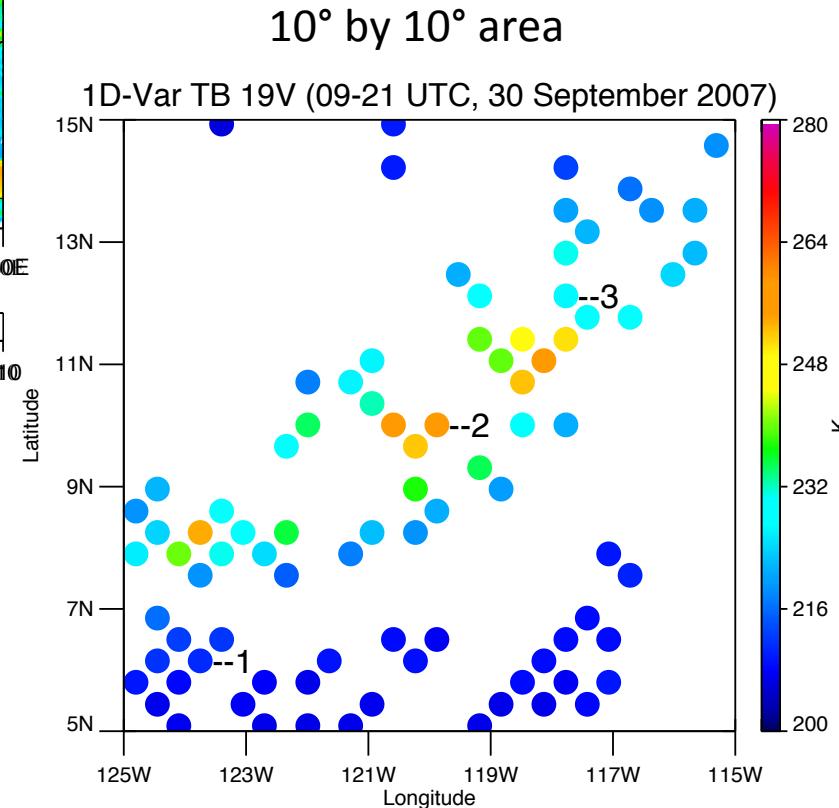
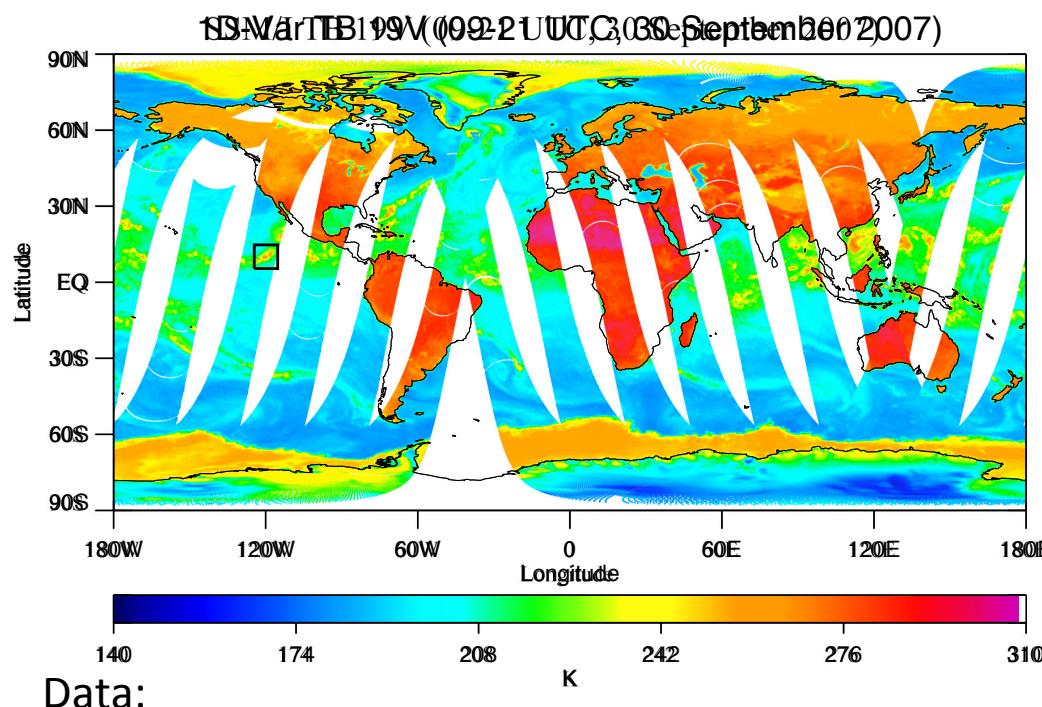
$$J(\mathbf{x}) = (\mathbf{x} - \mathbf{x}_b)^T \mathbf{B}^{-1} (\mathbf{x} - \mathbf{x}_b) + [\mathbf{y} - H(\mathbf{x})]^T \mathbf{R}^{-1} [\mathbf{y} - H(\mathbf{x})]$$

*thermodynamic profiles*

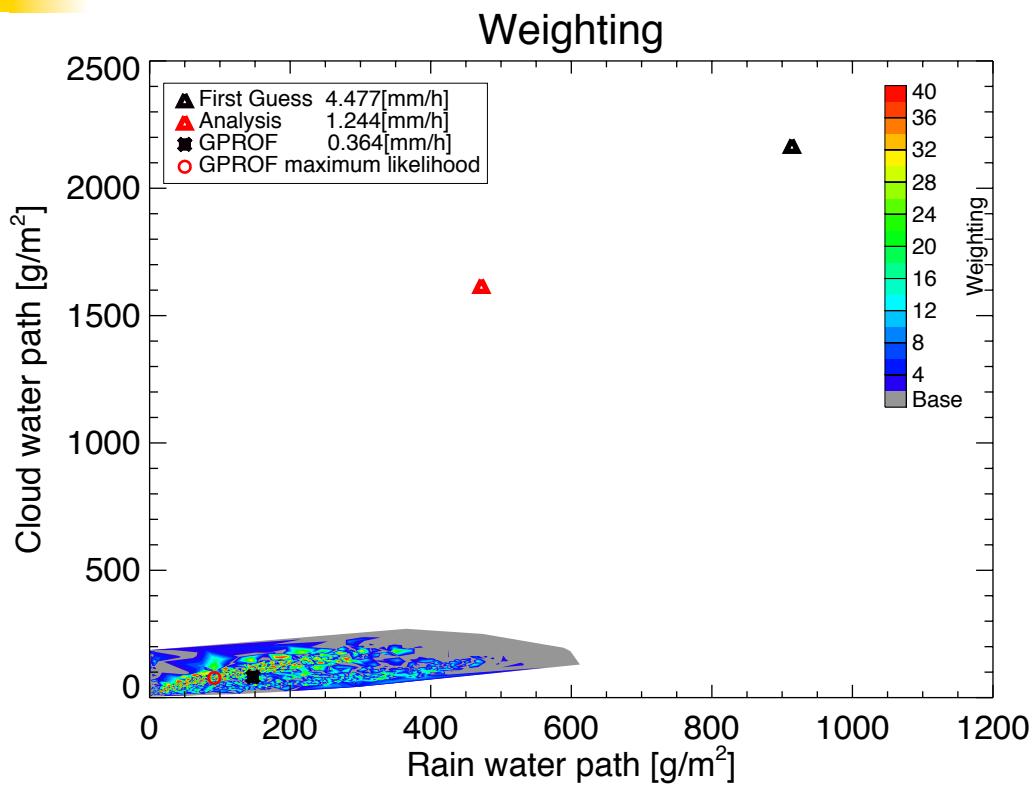
- Constrained by observationally generated *a-priori* database consisting of PR/TMI observations and CRM simulations
- $\mathbf{x}$ : microphysical profiles

- Constrained by ECMWF model's First Guess (FG) and the 1D cloud model
- $\mathbf{x}$ : thermodynamic profiles
- Only channel 19h, 19v, and 22v used.

# Case studies



# Pixel 3

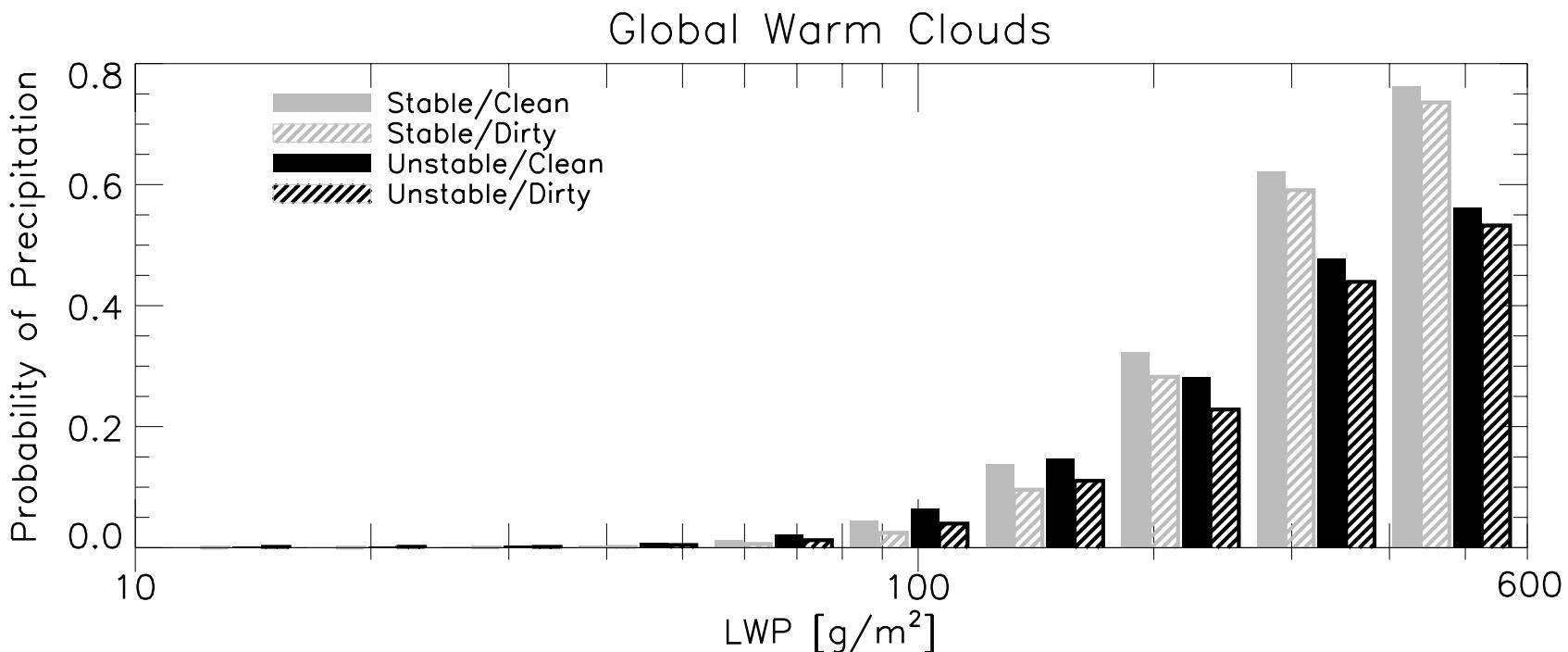


- FG  $T_b$  negative → too much emission
- Analysis reduces both CWP and RWP
- $T_b$ s match while microphysics has discrepancy

$T_b$ departures (K)	19V	19H	22V
GPROF maximum likelihood departures	-0.191	-1.105	-0.222
ECMWF 1D-Var FG departures	<b>-13.212</b>	<b>-23.246</b>	<b>-4.788</b>
ECMWF 1D-Var analysis departures	<b>-0.684</b>	<b>0.603</b>	<b>-1.809</b>

$T_b$	✓
CWP/RWP	✗

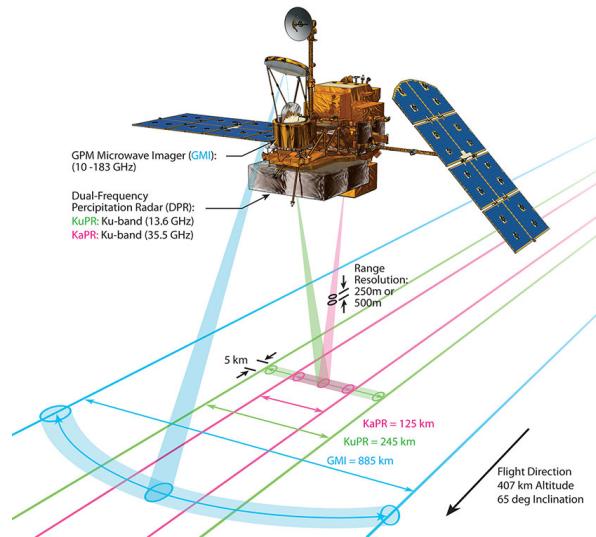
# Probability of Precipitation and Water Path



- Dependence on thermodynamic stability greater than that of aerosol
- POP decreased by ~5% in dirty air regardless of LWP

# The Global Precipitation measurement (GPM) Mission

## Feb 14, 2014 Launch Expected



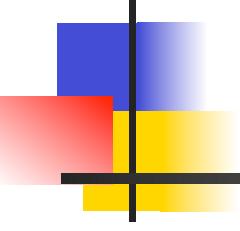
NASA/JAXA contribute Core Satellite  
Climate Analysis  
Precipitation Physics

GPM Core Satellite carries:

- a dual-frequency radar &
- a passive microwave imager with high frequency capabilities

*Constellation radiometers are contributed by any agency to produce the frequent sampling required by many applications.*





## *Conclusion (2012)*

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- GPM will help reduce uncertainty in absolute differences between radiative fluxes and precipitation.
- GPM should help resolve differences in climate sensitivity between Radar and Radiometer.
- We continue to look for robust ancillary information that describes precipitating clouds in a self similar manner – argue that radiometers by themselves, do not have enough information content to distinguish small changes in cloud properties from changes in surface precipitation.
- Physical retrieval schemes allow for validation of model processes – not simply model output.